2.5.1.2   Operations Effects

2.5.1.2.1   Increased Upstream Temperature

2.5.1.2.2   Redd Dewatering

2.5.1.2.3   Redd Scour

2.5.1.2.4   Stranding

2.5.1.2.5   North Delta Diversion Intake Screen Impingement and Entrainment

The PA includes construction of three north Delta diversion (NDD) intakes on the east bank of the Sacramento River between Clarksburg and Courtland, in Sacramento County, California. The intakes are designed as on-bank screens that would minimize the risk of fish entrainment into the intakes. Water will be diverted from the Sacramento River by gravity into the screened intake bays and routed from each bay through multiple parallel conveyance box conduits to the sedimentation basins. Flow meters and flow control sluice gates will be located on each box conduit to ensure limitations on approach velocities and that flow balancing among the three intake facilities is achieved (BA Section xx).

The screen length is 1,350 feet each at two (Intakes 2 and 5) of the three intakes and 1,110 feet at the third intake (Intake 3) (Table **Error! No text of specified style in document.**-1), with a combined total of 3,810 feet. When fish migrate past the fish screens, there are three general sources of potential impacts that may be caused by the new diversion structures and their operations. The first category of impacts are those that can typically result from the operation of large diversions such as entrainment and impingement of fish that come in contact with the facility as water is being diverted, possibly resulting in fish injury or mortality. The second category includes those impacts that may result from the existence of large concrete/steel structures in the river, such as increased predation and loss of shoreline habitat features. The third category of impacts are those associated with the diversion of large quantities of water from the river, which can affect flow patterns, hydrodynamics, and habitat features or ecological processes that are dependent on river flows.

*Table **Error! No text of specified style in document.**-1. Fish screen dimensions at the north Delta diversion intakes*

Intake	Location on Sacramento River	Screen Height (ft)	Screen Width (ft)	Number of Screens	Total Length of Screens (ft)
Intake 2	RM 41.1 38.40541, -121.51452	12.6	15	90	1,350
Intake 3	RM 39.4 38.38209, -121.51991	17.0	15	74	1,110
Intake 5	RM 36.8 38.35057, -121.53302	12.6	15	90	1,350

Source: BA Table 3.2-6

Juvenile Salmonid Entrainment through Screens

The proposed fish screens, consisting of vertical profile bars made from stainless steel, have a maximum opening of 0.069 inches (1.75 millimeters). Juvenile fish with a head width of less than or slightly greater than 1.75 millimeters could go through screen openings and get entrained into the intakes. It is possible that juvenile fish larger than the size of the fish screen openings

may pass through the fish screen if they become impinged on the fish screen and, during the process of trying to free themselves, change their orientation and are pulled through the fish screen openings by the current passing through the slot openings of the fish screen. Also, juvenile fish that exceed the minimum size criteria for exclusion and that are impinged on the fish screen may pass through the fish screen if they are pushed through by the screen cleaner brushes (ICF International 2015, Greenwood 2016).

It has been observed that a 32-millimeter Chinook salmon juvenile and a 41-millimeter lamprey ammocoete were entrained to the Freeport water intakes that have the 1.75-millimeter-opening vertical profile bar screens (ICF International 2015). Using estimated head width values for Chinook salmon derived from the fork length and head width measurements provided by Mueller et al. (1995), the entrained 32-millimeter Chinook salmon would have a 3.8 millimeter head, which is much larger than the screen openings. Based on this information, we are assuming for purposes of our analysis that juvenile fish with up to a 3-mm head width could go through the proposed fish screens, the estimated maximum fork length of the entrained juveniles would be 29 millimeters for Chinook salmon and 23 millimeters for rainbow trout.

The proposed fish screens, when meeting specific design criteria, have shown guidance efficiencies of greater than 98% for juvenile salmonids (i.e., less than 2% entrainment) (National Marine Fisheries Service 2011a). In a laboratory study, one out of 25 trout (*Salvelinus confluentas*) fish was entrained through the 1.75-millimeter opening of a vertical profile bar fish screen, implying a four percent entrainment rate. This fish was the smallest (23.0 millimeters) tested in the experiment (Zydlewski and Johnson 2002). From a field study, two percent juvenile cutthroat trout (*O. clarki*) (20–40-millimeter total length) were entrained through a fish screen on irrigation canals in the Bitterroot River basin, Montana (Gale *et al.* 2008).

Juvenile Salmonid Impingement on Screens

Impingement refers to the consequence of a situation where the approach velocity exceeds the swimming capability of a fish, creating injurious contact with the vertical bars of the fish screen. Whether or not impingement would occur depends on screen approach velocity, screen sweeping velocity, and the swimming capacity of juvenile fish.

Approach velocity is the vector component of the channel's water velocity immediately adjacent to the screen face that is perpendicular to and upstream of the vertical projection of the screen face, calculated by dividing the maximum screened flow by the effective screen area. All intakes in the PA will be sized to provide approach velocities at the fish screen of less than or equal to 0.20 feet/second, which is targeted at delta smelt and more stringent than the approach velocity criterion for juvenile Chinook salmon (i.e., 0.33 feet/second) (National Marine Fisheries Service 1997). Fish screens with approach velocities less than or equal to 0.33 feet/second would minimize screen contact and impingement of juvenile salmonids. Note that the minimization is assumed for healthy juvenile fish. For those fish that are already exhausted from trying to avoid the screen for long durations, they might be more vulnerable to screen contact and impingement. In order for the approach velocity to effectively deter juvenile fish, the screen design must provide for nearly uniform flow distribution over the screen surface. Uniform flow distribution avoids localized areas of high velocity, which have the potential to impinge fish. Uniformity of approach velocity is defined as being achieved when no individual approach velocity measurement exceeds 110 percent of the criteria (National Marine Fisheries Service 2011a).

Sweeping velocity is the vector component of canal flow velocity that is parallel and adjacent to the screen face, measured as close as physically possible to the boundary layer turbulence generated by the screen face. The BA did not provide information about what sweeping velocities should be achieved to minimize the potential impact to listed species, but indicated that Appendices 5A and 5B describe the assumptions used in modeling the sweeping velocity restrictions on the north Delta diversion. Fish screens must have sweeping velocity greater than the approach velocity. NMFS recommended that sweeping velocity be at least 0.8 feet/second and less than 3 feet/second (National Marine Fisheries Service 2011).

Study results indicate that juvenile fish impingement and associated mortality occur at screened facilities, but at low rates. Swanson et al. (2004b) conducted laboratory studies and found that juvenile Chinook salmon experienced frequent contact with a 2.3-millimeter vertical wedge wire screen, but no more than 0.3 percent test fish were impinged (defined as prolonged screen contacts greater than 2.5 minutes), and the overall mortality rate was less than one percent. Approach velocities within the range tested had no detectable effects on the behavior, performance, or survival of juvenile Chinook salmon exposed to the simulated fish screen. Manipulation of the sweeping flow component of screen flow criteria appears to offer an effective strategy for facilitating the passage of exposed fish by the screen as well as minimizing the probability of screen contact (Swanson et al. 2004a).

Another laboratory experiment using a vertical profile bar screen (1.75 millimeters openings) and bull trout fry (25.0 millimeters median total length) showed an impingement rate of 12 percent and survival rate of 100 percent. In this study, impingement was defined as extended contact (greater than one second) with the test screen (Zydlewski and Johnson 2002).

In a field study, juvenile salmonid injury and mortality were examined for vertical profile bar screens (1.75-millimeter opening) at John Day Dam. Note that these screens consist of a quite different configuration than those proposed for the NDD because they guide fish upward toward the bypass orifice. The study results indicated an average injury (greater than 20 percent descaling) of 2.8 percent and average mortality of 3.5 percent for yearling Chinook salmon, and 2.2 percent injury and 3.9 percent mortality for subyearing Chinook salmon (Brege et al. 2005), with an average of 2.5 percent for injury and 3.7 percent for mortality. These results likely represent the high end of juvenile fish injury and mortality rates at vertical profile bar screens.

Potential fish impingement was monitored at the Freeport Regional Water Authority's intake on the Sacramento River for a total of nearly 50 hours of DIDSON/ARIS camera monitoring and 9 hours of diver observations during two days in April of 2012, 2013, and 2014 (ICF International 2015, Greenwood 2016). No fish were observed by the divers or with the Dual-frequency Identification sonar (DIDSON) and adaptive resolution imaging sonar (ARIS) sonar cameras to be impinged on the fish screen. Several factors may play a role in explaining why no fish were observed to be impinged on the fish screens: low approach velocities (0.02 to 0.16 feet/second), limited field of view with the DIDSON/ARIS sonar camera, limitations associated with the sonar camera, and poor underwater visibility during the dive surveys. Limited field of view of the fish screen panel being monitored likely reduced the chances of observing an impingement event. The estimated area of the fish screen panel viewable with the DIDSON/ARIS sonar camera was 31.5 square feet in WY 2012, 26 square feet in WY 2013, and 24 square feet in WY 2014, and represented 29 percent, 24 percent, and 22 percent, respectively, of the entire area of the fish screen panel being monitored. The slightly less area of

the fish screen that was viewable with the ARIS sonar camera during WY 2013 and WY 2014 monitoring was the result of placing the higher resolution ARIS sonar camera closer to the fish screen panel in an attempt to observe the behavior of fish smaller than 30 millimeters (30 millimeters was the smallest fish that could be confidently identified with the DIDSON sonar camera during WY 2012 monitoring) (ICF International 2015).

2.5.1.2.5.1 Salmonids Exposure and Risk

Temporal Distribution of Juvenile Salmonids

Juvenile winter-run will migrate from the Sacramento River and pass the NDD intakes from mid-October to mid-April. There are two juvenile migration peaks: late November to late December and early February to late March. Juvenile spring-run enter from the Sacramento River to the Delta as early as December, and migration continues through early May. It shows peak migration to the Delta from mid-March to late April (He and Stuart 2016, unpublished data). Juvenile fall-run Chinook salmon are expected to be present in the Delta from December through August. Juvenile steelhead from the Sacramento River enter the Delta in late January and their migration continues through April. There are two peaks of juvenile steelhead migration: one from mid-February to mid-March and the other in April (He and Stuart 2016, unpublished data). The average size (fork length) of salvaged salmonid juveniles at the fish salvage facilities from 1993 to 2012 is 74 millimeters for fall-run sized juveniles, 95 millimeters for spring-run sized juveniles, 136 millimeters for winter-run sized juveniles, 156 millimeters for late fall-run juveniles, and 250 millimeters for steelhead juveniles (He and Stuart 2016, unpublished data).

Vertical Distribution of Juvenile Salmonids

Both laboratory and field studies have shown that emigrating juvenile salmoninds tend to be surface-oriented and often concentrate less than 49 feet deep, but can occur throughout the water column. Yearling Chinook salmon tend to emigrate deeper than steelhead (Carter et al. 2009, Smith et al. 2010). Klimley et al. (2010) observed a positive correlation between the frequency of salmonid smolt detections and depths ranging from 3.3-37 feet. This relationship was not evident, however, in waters deeper than 37 feet. During 2007–2008, Chinook salmon and steelhead smolts were detected in water ranging from 6–8 meters in depth along the eastern span of the San Francisco-Oakland Bay Bridge. Three dimensional positioning from mobile tracking JSATS fish in the Columbia River estuary indicated that Chinook salmon migrated through the lower Columbia River at 13.5–34.4 feet for yearlings and 15–90 feet for subyearlings (Carter et al. 2009). The water depth in the river channel at Intake 5 would be expected to be 26 feet or more 10 percent of the time, 20 feet or more 50 percent of the time, and 17 feet or more 80 percent of the time (Greenwood 2016). This implies that emigrating juvenile salmonids from the Sacramento River could be impacted by the entire height of the intake screens in the PA.

Horizontal Distribution of Juvenile Salmonids

The horizontal distribution of emigrating juvenile salmonids varies with the size of juvenile fish. Capture studies in the Columbia River (both the free flowing section and the estuary) have documented use of deeper offshore main channel habitats by larger yearling Chinook salmon and steelhead, whereas smaller juvenile fish, such as subyearling Chinook salmon, use the shallower water closer to shore (Carter et al. 2009, Smith et al. 2010).

It has been observed in the Sacramento River (within the Delta) that at night when juvenile salmon were actively moving, the horizontal distribution of juvenile salmon was more concentrated in the outside bend of the river, which presumably resulted from centrifugal and pressure forces in the outside bend. During daytime when juvenile salmon were likely holding, however, they tended to distribute more on the inside bend, as illustrated at Clarksburg Bend (based on Burau et al. 2007) (Greenwood 2016). Collectively, this indicates a possible 50/50 distribution close to the east and west river banks. The three diversion intakes in the PA are located within straight reaches of the river or mild outside bends to minimize complex flow patterns, sedimentation, and excessive scour. It is likely that subyearling winter-run would use near-bank habitat for rearing as monitoring data indicated that they rear in the Delta for 57 days on average. On the contrary, juvenile spring-run would likely spend a shorter time (26 days) rearing in the Delta, and even less time for juvenile steelhead (7 days) in the Delta (He and Stuart 2016, unpublished data).

Although there are no available data that address how on-bank water diversions influence or change the horizontal distribution of emigrating salmonid juveniles passing large diversion intakes, we assume that a larger (than normal) proportion of the emigrating juveniles would be drawn to the diversion intakes because of large volumes (up to 3,000 cfs) of water pulling to each of the diversion intakes at velocities up to 0.2 feet/second. Therefore, it is likely that up to one half of the emigrating juvenile salmonids would be expected to pass close to the intakes and are subject to impacts from the screens such as impingement and entrainment.

Entrainment of Juvenile Salmonids at the NDD Intakes

Using one percent entrainment rate and 50 percent emigrating juvenile salmonids subject to the impact of the screens, the quantity of juveniles affected by screen entrainment is 0.5 percent of a population.

Impingement of Juvenile Salmonids at the NDD Intakes

Using 2.5 percent injury and 3.7 percent mortality (Brege et al. 2005) for juvenile salmonids and 50 percent emigrating juveniles subject to the impact of the screens, the quantity of juveniles injured and killed by screen impingement is 1.25 percent and 1.85 percent, respectively, of a population.

Juvenile Salmonid Injury and Mortality at One NDD intake

Juvenile salmonid injury would be 1.25 percent. The combined mortality from entrainment and impingement would be 2.35 percent.

Adverse Effects of the Three NDD Intakes on Juvenile Salmonids

Assuming that the effects of the three intakes were additive, the total adverse effects of the three intakes on juvenile salmonids would be 3.75 percent for injury and 7.05 percent for mortality. We assume that the screen injured juvenile salmonids at the first or second intake may be subject to the impacts of the screens at the second and third intakes. However, in calculating juvenile salmonid mortality, the killed juveniles at the first or second intake are not counted for the impacts at the second or third intakes.

For a lower proportion (e.g., 33 percent or 25 percent) of a population subject to the screen impacts, the lower adverse effects on a population would be expected (Table **Error! No text of specified style in document.**-2).

*Table **Error! No text of specified style in document.**-2. Estimated adverse effects of the NDD intake screens on juvenile salmonids*

Entrainment Rate	Impingement Injury Rate	Impingement Mortality Rate	Impacted Proportion of Population	A Proportion Entrainment	B Proportion Impingement Injury	C Proportion Impingement Mortality	Sum A-C Estimated Take for 1 Intake	Estimated Take for 3 Intakes
0.01	0.025	0.037	0.50	0.0050	0.0125	0.0185	0.0360	0.104
0.01	0.025	0.037	0.33	0.0033	0.0083	0.0122	0.0238	0.0697
0.01	0.025	0.037	0.25	0.0025	0.0063	0.0093	0.01810	0.0533

2.5.1.2.5.2 Green Sturgeon Species Exposure and Risk

Entrainment of juvenile green sturgeon will not occur because the proposed screen opening will protect juvenile green sturgeon because they are much larger than juvenile salmonids at the time that they are migrating past the NDD. Impingement of juvenile green sturgeon may occur due to their behavior causing them to come into contact with the screens. Note: Additional information on this from DWR received too late to incorporate in this version.

2.5.1.2.6   Increased Predation Risk

2.5.1.2.6.1 Permanent In-Water Structures [Present Post-Construction](Section not complete)

The PA will result in new permanent structures in the river channel at the three NDDs and at the HOR gate. These include fish screens, XYZ. The effects of bulkheads, piers, pilings, and other over- and in-water structures on salmonids in the northwest were reviewed by Kahler et al. (2000) and Carrasquero (2001). Kahler et al. (2000) described how shoreline alterations could potentially increase the rate of predation on juvenile Chinook salmon by 1) reducing prey refuge habitat by modifying the structure of the shoreline; 2) providing concealment structures for ambush predators such as bass and sculpin; 3) creating enough structure to reduce bass home range sizes; 4) providing artificial lighting that allows for around-the-clock foraging by predators; 5) increasing migration route lengths and therefore predator exposure for smolts and rearing fry; and 6) increasing the bass population by increasing the amount of potential bass spawning habitat. Adult migrants are not expected to be adversely affected because they are less vulnerable to predation from resident predators in the Delta system.

Vertical bulkheads or retaining wall sites tend to be deeper, primarily because the structures are usually placed below the ordinary high water mark and then backfilled (Kahler et al. 2000 and Carrasquero 2001). This effectively pushes the shoreline out from its original location, which results in a corresponding increase in water depth along the face of the structure outside the shallow littoral zone. Given that out-migrating juvenile salmonids (particularly Chinook salmon) use shallow-water habitats for rearing, foraging, and migration, retaining walls may potentially disrupt juvenile salmonid migration, reduce prey resource availability, and increase exposure to predators found in deeper water.

Vertical bulkheads or retaining walls also alter the flows along the bank, enhancing scour along the foot of the structure. This can create depressions along the outer margin of the in-water

structure which may attract predators and provide holding areas for larger predatory fish. Prey fish may attempt to avoid the shallow-water increased predation risk by moving into deeper water where there is increased vulnerability to predation by larger predators and less refuge habitat.

Vertical bulkheads and retaining walls also create shaded areas along their face during certain periods of the day which create hiding areas for predators and prey that conceal them from fish in the lighted zone outside of the area impacted by the shaded area. Such behavior by fish creates a temporal and spatial overlap of predators and prey in the shaded zone, as well as enhancing the success of predator ambush attacks on prey outside of the shaded zone (Kahler et al. 2000, Carrasquero 2001).

Vertical pilings will provide alterations to the local flow field by disrupting the flow, creating eddies downstream of the piling and other microhabitats where predatory species may preferentially hold (Carrasquero 2001). These pilings also attract juvenile salmonids trying to avoid the local river currents. Therefore pilings can create and increased the overlap of predator and prey in a localized area, increasing the predation risk for the prey species that are not provided local refuge habitat. Similar to bulkheads and walls, pilings can create shade that attracts predators (Kahler et al. 2000, Carrasquero 2001).

2.5.1.2.6.1.1 North Delta Intakes

By the very nature of being permanent, the in-water infrastructure of the NDD will be present throughout the year and will overlap with the occurrence of several life stages of listed fish species that are present in that region of the Sacramento River channel.

The permanent in-water infrastructure for the three NDD include sheet pile training walls extending from the levee face to the intake screens; cut-off sheet pile wall running the length of the screen forming the edge of the sill; fish screens with refuge areas located between screen bays; floating debris boom along outside face of the fish screens; debris boom piles to support floating debris boom. These structures create habitat that provides holding and cover for predators.

The footprint of each intake structure, including cofferdams, transition wall structures, and bank protection (riprap), would result in the permanent loss of approximately 6.6 acres of tidal perennial habitat and 1.02 linear miles of shoreline and associated riparian vegetation. At each intake location, these structures would encompass 1,600-2,000 linear feet of shoreline and 35 feet (5-7 percent) of the total channel width. In addition, riprap and artificial structures provide physical and hydraulic conditions that may attract certain predatory fish species such as striped bass, largemouth bass, smallmouth bass, and Sacramento pikeminnow and potentially increase their ability to ambush juvenile salmonids and other fishes.

The training sheet pile wall and vertical fish screens at the NDD constitute a permanent vertical bulkhead or retaining wall structure. Vertical bulkheads retaining walls lack habitat complexity, offering little refuge from predators. The NDD fish screen design described in the PA includes refuge areas between each set of screen bays; these are hypothesized to provide shelter to prey species such as juvenile salmonids from co-occurring predators. This technology is still nascent, and its efficacy is unknown.

The NDD fish screen design described in the PA includes a debris boom to deflect floating debris from the screens, particularly during high flow events. The debris boom consists of a floating boom anchored in place by vertical pilings that run the length of the intake structure several feet outboard of the screen face. The project will have three log booms ranging from 1,300-1,700 feet long, depending on intake location. Booms will be supported by 32-40 pilings at each intake location. Each piling and the associated floating log boom will provide both structure and shade in an offshore environment. This will likely attract both predators and prey.

Because the debris booms are designed to intercept floating debris and prevent damage to the fish screens, they can potentially accumulate debris to create a larger, more complex structure than the boom and pilings alone. During high flow periods, debris mass is expected to attract both predators and prey, and will continue to do so until the debris is removed. It is during these high flow events that juvenile salmonids will be moving downstream through the NDD locations, creating an overlap between predator and prey presence and increasing predation risk.

2.5.1.2.6.1.1.1   Winter-run Species Exposure and Risk

Detailed timing and spatial occurrence of winter-run Chinook salmon presence is described in section 2.5.1.1.1.1.1. Juvenile winter-run Chinook salmon can be found in the Delta near the NDD starting in October and continuing through April.

The location of the NDDs is found along the migratory corridor for all winter-run Chinook salmon juveniles and adults. As described above, the permanent NDD structures will create habitat and opportunity for larger predators, which is expected to result in adverse effects to juvenile winter-run Chinook salmon. It is difficult to quantify the extent of impacts to juvenile winter-run Chinook salmon expected to occur at the NDDs especially given the uncertainty related to the efficacy of proposed refugia and predator cover areas. Therefore, research and monitoring at these sites will be important to improve understanding of the potential extent of impacts.

2.5.1.2.6.1.1.2   Spring-run Species Exposure and Risk

Detailed timing and spatial occurrence of spring-run Chinook salmon presence have previously been described in section 2.5.1.1.1.1.1.2. Juvenile spring-run Chinook salmon can be found in the Delta near the NDD from November through May.

The location of the NDDs serve as a migratory corridor for all Sacramento River basin-produced spring-run Chinook salmon juveniles and adults. As described above, the permanent NDD structures will create habitat and opportunity for larger predators, which is expected to result in adverse effects to juvenile spring-run Chinook salmon. It is difficult to quantify the extent of impacts to juvenile spring-run Chinook salmon expected at the NDDs, therefore monitoring at these sites will be important to improve understanding.

2.5.1.2.6.1.1.3   Steelhead Exposure and Risk

Detailed timing of juvenile and adult CCV steelhead presence has previously been described in section ***Error! Reference source not found. Error! Reference source not found.***. Juvenile CCV steelhead are present in the Delta from November through June, with peak occurrence from January through March. Adult CCV steelhead from the Sacramento River basin begin to migrate upriver from the Delta in June, with increasing numbers of fish arriving from August through

September, before tapering off in October and November. Peak migration (approximately 69 percent of the annual run) occurs in September and October. Adult CCV steelhead from the San Joaquin River basin migrate into the Delta beginning in September and October, with peak migration occurring between November and January.

Detailed spatial occurrence for juvenile and adult CCV steelhead has been described previously in section *Error! Reference source not found. Error! Reference source not found.*. In summary, all adult and juvenile CCV steelhead must pass through the Sacramento River channel adjacent to the NDD intake locations during periods when Sacramento River flows do not overtop Fremont Weir. When the river flows exceed the crest elevation of the Fremont Weir (+33.5 feet above mean sea level) fish may pass over the weir through a crude fish ladder or over the top of the weir itself. This provides an alternative migratory route to the main stem Sacramento River channel for both downstream emigrating fish and for adults that may be moving upstream. High river flow conditions typically occur in late fall and winter in response to heavy precipitation events.

Juvenile steelhead will be exposed to any predators at the NDD. The distribution and timing of predatory fish, including striped bass, largemouth bass, smallmouth bass and Sacramento pikeminnow, overlap with the presence of juvenile steelhead at the NDD; all of these predatory fish are resident in the Sacramento River year round. Juvenile steelhead are expected to have similar responses to predation risks as described for salmon in Kahler et al. (2000), although outmigrating steelhead smolts are typically larger than outmigrating juvenile Chinook salmon and may have a slight reduction in risk. However, steelhead are expected to be adversely effected as they encounter an increased predation risk at the NDD. It is difficult to quantify the extent of impacts to juvenile steelhead expected at the NDDs, therefore monitoring at these sites will be important to improve understanding.

2.5.1.2.6.1.1.4   Green Sturgeon Exposure and Risk

2.5.1.2.6.1.1.5   Fall/Late fall-run Exposure and Risk

2.5.1.2.6.1.2   HOR Gate

An operable gate will be constructed at the HOR to prevent migrating juvenile salmonids (San Joaquin River-origin steelhead, spring-run Chinook salmon, and fall-run Chinook salmon) from entering Old River from the San Joaquin River, and thereby minimize their exposure to the CVP/SWP pumping facilities. The gate will be located in Old River approximately 400 feet downstream of the junction of Old River with the San Joaquin River. The gate will be 210 feet long and 30 feet wide, with a top elevation of +15 feet and include seven bottom-hinged gates, a fish passage structure, a boat lock, a control building, a boat lock operator's building, and a communications antenna.

Elements of the HOR gate construction will lead to adverse effects upon listed salmonids over the course of its operations. The base of the gate structure will consist of a concrete foundation poured over steel foundation piles set into the channel bottom during construction. It is anticipated that the steel sheet piles used to construct the cofferdam will be cut off above the channel invert at the level of the concrete foundation surface to create a raised sill, similar to the NDD fish screens. When the gate is operated the gates are raised either by hydraulic pistons or by a pneumatic bag to block the flow of water through the gate location. When the gates are not

in operation they are lowered and lay flat on the concrete foundation. In this closed position, when the gates are lying flat on the bottom, there will be a turbulent layer of water flow adjacent to the surface of the gates caused by irregularities in the surface of the gate structure. The raised sill is anticipated to create a rotating eddy in front of and behind the foundation of the gates as the ambient river flow goes over the top of the gate structure when the gates are in their lowered position and flat against the foundation floor. This will allow fish, including predators, to "sit" in this eddy and hold station both in front of and behind the foundation structure. In addition, as flow moves over the gate panels, the flow is anticipated to speed up, much like air moving over a the curved surface of a wing, and then slow down and separate once it reaches the trailing edge of the gate structure, creating a series of small eddies along the shear line between moving water and stationary water behind the gate structure. It is anticipated that this will have an adverse effect upon salmonid survival by increasing the vulnerability to predation of any salmonids moving through the location of the gates due to the nature of the velocity discontinuities and rotational eddies found in this flow field.

Flow along the edges of the boat lock channel and levee embankment where the gate structure ties into the levee face will have small fields of turbulent flow and eddies associated with the sheet pile walls used to construct these structures. As stated earlier in the CCF section regarding pile driving, the sheet pile identified for use in this project will have large indentations in the constructed wall. The individual sheet piles are interlocking and will create a depression 18 inches deep by approximately 40 inches long for every two interlocking piles. Within each indentation, there will be a small eddy allowing fish to hold, including predators, but will not provide suitable habitat that would form refugia for small fish such as juvenile salmonids to hide from predators. The sheet pile walls will enhance the vulnerability of listed salmonids to predation from predators holding along these walls. Thus, the sheet pile walls as proposed, are likely to adversely affect the survival of salmonids passing through this location.

The operation of the boat lock may lead to the "accidental" passage of juvenile salmonids in the San Joaquin River into the channel of Old River below the location of the gates. Passage into Old River will expose these fish to predators in the Old River corridor and eventually, the potential entrainment into the SWP and CVP export facilities and their associated predation and survival elements. When the gate is operating and flows from the San Joaquin River are blocked, the flows downstream of the gates on Old River are reduced, and the local hydraulics immediately downstream of the gate would create conditions that are expected to enhance predation. Lowered velocities and eddies created by the gate structure and boat locks would slow down passage of any juvenile salmonid in this reach and increase the exposure time to any predators holding immediately below the dam-like gate structure thus increasing the vulnerability to predation and enhancing the success of a predation event (Sabal et al. 2016, Blackwell and Juanes 1998, Tucker et al. 1998)).

The docks and pilings associated with the upstream and downstream sides of the boat lock will also create habitat which may adversely affect the survival of juvenile salmonids passing these structures. As previously discussed in the predation risks for interim structures, pilings and the shaded areas beneath docks can create habitat that attracts both predators and prey, thus increasing the overlap of the predator's presence with their prey. However, this structure does not create habitat that can serve as protective refugia for the smaller prey fish and thus enhances the interaction between predator and prey and likely increases the success of the predation event leading to an adverse outcome in terms of salmonid survival.

The proposed fish ladder providing passage for adult salmonids from Old River to the San Joaquin River when the gates are in their raised position may also adversely affect juvenile salmon survival. The gates are projected to be raised during the winter and spring seasons when juvenile steelhead and juvenile fall-run and spring-run Chinook salmon are emigrating downstream from the San Joaquin River basin. During this period of time, it is expected that some adult steelhead, as well as adult spring-run Chinook salmon from the reintroduction effort will be attempting to migrate upriver to spawn in the basin's tributaries. This requires the fish passage ladder to be open to accommodate adult passage. When the ladder is open, the flows through the ladder structure may encourage juvenile fish to follow this cue and pass downstream through the ladder. As proposed, the fish ladder design has a long, narrow passage from the San Joaquin river side to the actual opening of the ladder which is constructed of sheet pile walls. It is likely that predators will hold in this channel. In addition, the entrance and exit of the fish ladder is associated with the location of the pilings and docks for the boat lock, creating yet another overlap of predators and prey. Juvenile fish that successfully transit the fish ladder structure, still have to pass through the downstream area described for the boat lock in the previous section, with its elevated predation risks.

The physical location of the gate structure may increase predation risks for emigrating juvenile salmonids from the San Joaquin River basin. As designed, the gate location is set back approximately 400 feet into Old River from the junction between the San Joaquin River and Old River. When the gates are raised, and the flow into Old River is blocked, it is expected that the flow from the San Joaquin River will form a large eddy in front of the closed gate. This large eddy will create hydraulic conditions that will aggregate both predators and prey and increase the period of overlap between the two groups. By increasing the likelihood of spatial and temporal co-occurrence, the risk of successful predation events increases. Furthermore, there is a known scour hole adjacent to the HOR gate location, just downstream of the junction on the left bank of the San Joaquin River that attracts predators and creates a significant predation hotspot for emigrating salmonids. Thus, the pre-existing predation hotspot, combined with a new area that is likely to aggregate predators and prey, will only exacerbate the predation risk in this confined area as predators can easily move from one spot to the other. Moving the gate location closer to the junction to alleviate the size of the eddy circulation will reduce both the temporal and spatial area of overlap between predators and prey, thus reducing the likelihood of successful predation events occurring.

2.5.1.2.6.1.2.1　Winter-run Exposure and Risk

2.5.1.2.6.1.2.2　Spring-run Exposure and Risk

Detailed timing and spatial occurrence of spring-run Chinook salmon presence have previously been described in section 2.5.1.1.1.1.1.2. Juvenile spring-run Chinook salmon can be found in the Delta near the HOR gate from November through May.

The location of the HOR gate serves as a migratory corridor for all San Joaquin River basin-produced spring-run Chinook salmon juveniles and adults. As described above, the permanent HOR gate structure (and boat lock) will create habitat and opportunity for larger predators, which is expected to result in adverse effects to juvenile spring-run Chinook salmon. It is difficult to quantify the extent of impacts to juvenile spring-run Chinook salmon expected at the HOR gate, therefore monitoring at these sites will be important to improve understanding.

2.5.1.2.6.1.2.3 Steelhead Exposure and Risk

The timing and spatial distribution of CCV steelhead has already been discussed in section ***Error! Reference source not found. Error! Reference source not found.***. Since the HOR gate is a permanent structure that, once constructed, will be present year round, it will coincide with the presence of any CCV steelhead in adjacent waterways. Only steelhead originating in the San Joaquin River basin upstream of the Delta are expected to be exposed to the HOR gate and associated structures because of the gate location. Fish from the Sacramento River basin and east side tributaries are not expected to be present at the HOR gate location.

The HOR gate is expected to affect steelhead in the south Delta. The structure is expected to prevent fish from entering the Old River migratory corridor and reduce the potential for increased predation and mortality associated with these waterways and the operations of the SWP and CVP export facilities. However, the proposed design and operations of the gate will create several habitat elements that will increase the potential for predation of emigrating steelhead. The adverse effects associated with the gate design and its operations may be avoided or minimized through design modifications. However, as proposed, the structure introduces a potential predation risk that is expected to be adverse to the species.

2.5.1.2.6.1.2.4 Green Sturgeon Exposure and Risk

2.5.1.2.6.1.2.5 Fall/Late fall-run Exposure and Risk

2.5.1.2.6.2 Turbidity

2.5.1.2.6.2.1 Winter-run Exposure and Risk

2.5.1.2.6.2.2 Spring-run Exposure and Risk

2.5.1.2.6.2.3 Steelhead Exposure and Risk

2.5.1.2.6.2.4 Green Sturgeon Exposure and Risk

2.5.1.2.6.2.5 Fall/Late fall-run Exposure and Risk

2.5.1.2.6.3 Flow or Migration Route

2.5.1.2.6.3.1 Winter-run Exposure and Risk

2.5.1.2.6.3.2 Spring-run Exposure and Risk

2.5.1.2.6.3.3 Steelhead Exposure and Risk

2.5.1.2.6.3.4 Green Sturgeon Exposure and Risk

2.5.1.2.6.3.5 Fall/Late fall-run Exposure and Risk

2.5.1.2.7 Reduced In-Delta Flows

The Sacramento-San Joaquin Delta is an inverted Delta that consists of many channels and distributaries before funneling into the Bay at Carquinez Strait. Delta inflow and tidal excursion counteract each other in the lower part of the estuary to influence channel velocity and proportional flow in the channels and distributaries anadromous fish rear and migrate through

Riverine flow is a key component of aquatic habitat and migratory success in the Delta. Flow affects several aspects of anadromous species behavior and survival given that the timing and quantity of flow influences spawning behavior, migration events, habitat use, predator evasion, and ultimately survival (Perry et al 2010, Michel et al 2013, del Rosario et al 2013, Fish et al 2010).

The studies also highlighted that there is a strong relationship between river flow and through-Delta survival, particularly in reaches where tidal influence begins to encroach on the mostly riverine areas of the lower Sacramento River during periods of low Delta inflow (Perry et al in prep, Perry et al 2010). These studies are extremely useful in providing insight into the mortality risk for Chinook salmon migrating through the Delta.

 Assessing survival and migratory changes for Chinook salmon in the Delta with the operations of the PA relies on understanding of inflows into and hydrodynamics of the Delta. Many of the CWT and acoustic tag studies conducted in the Delta released fish into the Sacramento River just above or below the Freeport area. Sacramento River flows at Freeport (USGS gauge 1447650) and just downstream of the junction with Georgiana Slough (USGS gauge 11447905) as well as the Delta Outflow Index (DWR Dayflow_DOI) are often used to analyze flow-related survival for such studies. Flow at Freeport is also used as a metric to assess differences in survival, migration routing, travel time, and occurrence of reverse flow in the junction of the Sacramento River just below Georgiana Slough (Perry et al 2016 in prep, Perry et al 2015). Analyses used in this biological opinion will include assessment of Delta hydrodynamics as drivers or correlates to salmonid migration route selection and flow-related survival.

2.5.1.2.7.1 Travel Time

Patterns of fish migration are tied to flows, and are influenced by velocities of flow and reverse flows. When velocities along migratory corridors are reduced, outmigrating juvenile salmon (i.e., smolts) take a longer time to travel and are more likely to be vulnerable to increased predation risk in the Delta. The amount of time an outmigrating juvenile salmon travels through migratory corridors in the Delta is an indicator of predation risk, with longer travel time through the Delta resulting in higher predation risk.

2.5.1.2.7.1.1   Channel Velocity Analysis

The BA provides analysis of key salmonid migration routes and channel junctions in the Delta and the effects of PA operations on the hydrodynamics of those routes and junctions (BA Section 5.4.1.3.1.2.1.1). The analysis in the BA uses DSM2 modeling to evaluate the NAA and PA for 1) differences in magnitude of channel velocities, 2) differences between magnitude of negative velocities, 3) and differences in the proportion of time each day that velocity was negative in the study channels. Table 5.D-34 describes the channels used in the velocity analysis, as well as the hypothesized importance of a particular channel on salmonid migration and survival.

These analyses provide information on the hydrodynamic conditions that an outmigrating fish will experience. Because flow velocity can affect fish travel time, and therefore the potential risk of exposure to predation, results from these analyses can indicate whether the physical conditions are more or less supportive in facilitating swift smolt outmigration.

DSM2 Channel	Description	Hypothesized importance
21	San Joaquin River downstream of the head of Old River.	Fish in this region have avoided entering the interior Delta at Head of Old River and are in a potentially higher survival route, where survival may be influenced by river flow (velocity).
45	San Joaquin River near the confluence with the Mokelumne River.	Fish entering the San Joaquin River from the Sacramento River via Georgiana Slough and the DCC experience this area.
94	Old River downstream of the south Delta export facilities.	Fish attempting to move north from the south Delta experience are within the hydrodynamic footprint of the south Delta export facilities and are particularly susceptible to entrainment.
212	Old River upstream of the south Delta export facilities.	Fish moving through Old River experience conditions in this channel as they approach the facilities.
418	Sacramento River downstream of proposed NDD.	Fish moving down the Sacramento River could experience operational effects in this region (flow-survival relationships).
421	Sacramento River upstream of Georgiana Slough.	This region is where fish may enter the interior Delta from the Sacramento River, and there may be flow-survival relationships.
423	Sacramento River downstream of Georgiana Slough.	This region is where fish may enter the interior Delta from the Sacramento River, and river flow (velocity) may affect survival (i.e., there is a significant flow-survival relationship; Perry 2010).
DCC	Delta Cross Channel	Fish from the Sacramento River may enter the interior Delta through this channel.
379	Steamboat Slough	Fish using this route are not exposed to entrainment into Georgiana Slough and the DCC, and river flow (velocity) may affect survival (i.e., there is a significant flow-survival relationship; Perry 2010)
383	Sutter Slough	Fish using this route are not exposed to entrainment into Georgiana Slough and the DCC, and river flow (velocity) may affect survival (i.e., there is a significant flow-survival relationship; Perry 2010)

A limitation to this model, as also stated in the BA, is that differences in velocity may not directly correspond to biological outcomes in scenarios. Juvenile salmonids may show a selective tidal-stream transport that does not allow simple differences in velocity to translate into biological outcomes (Delaney et al. 2014). The uncertainty in these results limits their use to general trends in differences, such as decreased overall velocity, increased negative velocity, and a greater proportion of negative velocity as indicators of adverse effects to juvenile salmonids, including delayed migration or advection into migration pathways with higher mortality risk.

Though the operations of the PA have the potential to beneficially change channel flows in the Delta, the changes will depend on the extant conditions and specific PA operational conditions. The velocity analysis can indicate whether operations beneficially increase channel flows in ways that would reduce travel time and decrease the likelihood of exposure to less-suitable migration routes.

Tables 5.4-9, 5.4-10, and 5.4-11 show the results of the analyses of median channel velocity, median negative channel velocity, and median daily proportion of negative velocity values at the locations specified in Table 5.D-34. Results relevant to each species are discussed in the species-specific discussion of effects on travel time.

*Table **Error! No text of specified style in document.**-3. Median channel velocity as simulated by DSM2-HYDRO for the PA (BA Table 5.4-9).*

DSM2 Channel	Location	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
21	San Joaquin River downstream of HOR	W	0.263	0.264	0.001 (0%)	0.378	0.433	0.054 (14%)	0.473	0.533	0.060 (13%)	0.482	0.548	0.066 (14%)	0.428	0.493	0.065 (15%)	0.407	0.462	0.055 (13%)	0.330	0.355	0.025 (8%)
		AN	0.182	0.185	0.003 (2%)	0.239	0.295	0.056 (23%)	0.308	0.371	0.064 (21%)	0.295	0.368	0.073 (25%)	0.271	0.351	0.081 (30%)	0.254	0.331	0.078 (31%)	0.152	0.196	0.045 (30%)
		BN	0.115	0.119	0.004 (4%)	0.131	0.202	0.071 (54%)	0.265	0.318	0.053 (20%)	0.169	0.251	0.082 (49%)	0.199	0.286	0.087 (44%)	0.166	0.245	0.079 (47%)	0.097	0.118	0.022 (22%)
		D	0.087	0.089	0.002 (3%)	0.112	0.171	0.059 (52%)	0.167	0.223	0.057 (34%)	0.172	0.228	0.056 (32%)	0.167	0.234	0.067 (40%)	0.155	0.217	0.061 (39%)	0.090	0.110	0.020 (22%)
		C	0.085	0.086	0.001 (1%)	0.087	0.128	0.041 (47%)	0.120	0.167	0.048 (40%)	0.104	0.142	0.038 (37%)	0.099	0.134	0.035 (35%)	0.092	0.128	0.035 (38%)	0.076	0.083	0.008 (11%)
45	San Joaquin River near the confluence with the Mokelumne River	W	0.240	0.251	0.011 (4%)	0.432	0.488	0.056 (13%)	0.471	0.554	0.083 (18%)	0.452	0.550	0.098 (22%)	0.439	0.474	0.034 (8%)	0.394	0.430	0.036 (9%)	0.232	0.293	0.061 (27%)
		AN	0.140	0.155	0.015 (11%)	0.269	0.300	0.031 (11%)	0.334	0.368	0.034 (10%)	0.293	0.385	0.092 (31%)	0.298	0.324	0.026 (9%)	0.247	0.270	0.022 (9%)	0.142	0.171	0.030 (21%)
		BN	0.061	0.081	0.020 (34%)	0.131	0.191	0.060 (45%)	0.237	0.260	0.023 (10%)	0.168	0.197	0.029 (17%)	0.213	0.222	0.009 (4%)	0.172	0.186	0.014 (8%)	0.130	0.139	0.008 (6%)
		D	0.068	0.076	0.008 (11%)	0.118	0.149	0.031 (27%)	0.184	0.198	0.013 (7%)	0.192	0.203	0.011 (6%)	0.195	0.208	0.014 (7%)	0.158	0.172	0.014 (9%)	0.134	0.143	0.010 (7%)
		C	0.085	0.087	0.002 (2%)	0.092	0.111	0.020 (21%)	0.148	0.150	0.002 (1%)	0.152	0.161	0.010 (6%)	0.144	0.148	0.004 (3%)	0.122	0.126	0.004 (3%)	0.124	0.124	0.000 (0%)
94	Old River downstream of the south Delta export facilities	W	-0.250	-0.175	0.075 (30%)	0.004	0.227	0.224 (5831%)	0.036	0.448	0.412 (1138%)	0.052	0.505	0.454 (877%)	0.350	0.486	0.136 (39%)	0.296	0.453	0.157 (53%)	-0.110	0.170	0.279 (255%)
		AN	-0.358	-0.272	0.087 (24%)	-0.121	0.008	0.129 (107%)	-0.062	0.087	0.149 (240%)	-0.146	0.265	0.411 (282%)	0.189	0.230	0.041 (22%)	0.164	0.197	0.032 (20%)	-0.181	-0.061	0.120 (66%)
		BN	-0.446	-0.363	0.083 (19%)	-0.200	0.003	0.203 (101%)	-0.108	-0.051	0.057 (53%)	-0.171	-0.100	0.071 (42%)	0.109	0.061	-0.048 (-44%)	0.088	0.061	-0.027 (-30%)	-0.131	-0.077	0.054 (41%)
		D	-0.368	-0.321	0.046 (13%)	-0.213	-0.134	0.079 (37%)	-0.133	-0.086	0.047 (35%)	-0.097	-0.074	0.024 (24%)	0.067	0.047	-0.020 (-30%)	0.039	0.043	0.004 (11%)	-0.112	-0.043	0.069 (61%)
		C	-0.266	-0.222	0.044 (16%)	-0.214	-0.190	0.023 (11%)	-0.107	-0.108	0.000 (0%)	-0.019	-0.016	0.003 (16%)	0.056	0.034	-0.022 (-39%)	0.045	0.029	-0.015 (-35%)	0.035	0.052	0.017 (48%)
212	Old River upstream of the south Delta export facilities	W	0.682	0.701	0.018 (3%)	0.946	0.867	-0.079 (-8%)	1.120	1.036	-0.084 (-8%)	1.199	1.075	-0.124 (-10%)	1.171	1.074	-0.097 (-8%)	1.161	1.069	-0.093 (-8%)	0.666	0.621	-0.045 (-7%)
		AN	0.574	0.558	-0.016 (-3%)	0.705	0.578	-0.127 (-18%)	0.794	0.689	-0.105 (-13%)	0.818	0.754	-0.064 (-8%)	0.814	0.640	-0.174 (-21%)	0.805	0.612	-0.193 (-24%)	0.301	0.159	-0.142 (-47%)
		BN	0.493	0.465	-0.028 (-6%)	0.503	0.362	-0.141 (-28%)	0.713	0.555	-0.158 (-22%)	0.583	0.350	-0.234 (-40%)	0.657	0.387	-0.269 (-41%)	0.589	0.327	-0.262 (-44%)	0.132	0.047	-0.085 (-64%)
		D	0.445	0.428	-0.017 (-4%)	0.452	0.287	-0.165 (-36%)	0.541	0.378	-0.162 (-30%)	0.575	0.387	-0.188 (-33%)	0.584	0.363	-0.221 (-38%)	0.546	0.346	-0.200 (-37%)	0.113	0.037	-0.076 (-67%)
		C	0.418	0.394	-0.024 (-6%)	0.393	0.248	-0.145 (-37%)	0.467	0.300	-0.167 (-36%)	0.410	0.251	-0.159 (-39%)	0.378	0.235	-0.143 (-38%)	0.359	0.200	-0.160 (-44%)	0.009	-0.011	-0.020 (-229%)
365	Delta Cross Channel	W	0.016	0.016	0.000 (0%)	0.013	0.013	0.000 (1%)	0.014	0.014	0.000 (0%)	0.015	0.015	0.000 (1%)	0.016	0.016	0.000 (1%)	0.016	0.016	0.000 (2%)	0.422	0.471	0.049 (12%)
		AN	0.025	0.027	0.001 (6%)	0.014	0.014	0.000 (1%)	0.015	0.015	0.000 (2%)	0.015	0.015	0.000 (2%)	0.014	0.014	0.000 (2%)	0.013	0.013	0.000 (2%)	0.662	0.576	-0.087 (-13%)
		BN	0.036	0.037	0.001 (3%)	0.011	0.012	0.001 (5%)	0.013	0.013	0.000 (1%)	0.012	0.012	0.000 (1%)	0.012	0.013	0.000 (1%)	0.011	0.011	0.000 (2%)	0.667	0.613	-0.053 (-8%)
		D	0.043	0.043	0.000 (-1%)	0.011	0.011	0.000 (2%)	0.012	0.012	0.000 (0%)	0.013	0.013	0.000 (0%)	0.012	0.012	0.000 (0%)	0.010	0.011	0.000 (2%)	0.675	0.609	-0.065 (-10%)
		C	0.040	0.039	-0.001	0.010	0.010	0.000	0.011	0.011	0.000	0.010	0.011	0.000	0.010	0.010	0.000	0.008	0.009	0.000	0.535	0.518	-0.017

DSM2 Channel	Location	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
21	San Joaquin River downstream of HOR	W	-0.298	-0.295	0.003 (1%)	-0.246	-0.194	0.052 (21%)	-0.182	-0.133	0.049 (27%)	-0.166	-0.121	0.045 (27%)	-0.154	-0.104	0.051 (33%)	-0.187	-0.124	0.063 (34%)	-0.222	-0.205	0.017 (7%)
		AN	-0.334	-0.332	0.002 (1%)	-0.284	-0.233	0.051 (18%)	-0.246	-0.187	0.059 (24%)	-0.225	-0.170	0.055 (25%)	-0.194	-0.132	0.062 (32%)	-0.215	-0.149	0.066 (31%)	-0.267	-0.249	0.017 (7%)
		BN	-0.321	-0.317	0.004 (1%)	-0.309	-0.251	0.058 (19%)	-0.281	-0.220	0.061 (22%)	-0.258	-0.198	0.060 (23%)	-0.229	-0.167	0.061 (27%)	-0.249	-0.190	0.059 (24%)	-0.299	-0.287	0.012 (4%)
		D	-0.333	-0.330	0.002 (1%)	-0.318	-0.259	0.059 (19%)	-0.306	-0.250	0.057 (18%)	-0.309	-0.254	0.054 (18%)	-0.277	-0.226	0.051 (18%)	-0.291	-0.239	0.052 (18%)	-0.312	-0.301	0.011 (4%)
		C	-0.338	-0.337	0.001 (0%)	-0.341	-0.294	0.047 (14%)	-0.317	-0.266	0.051 (16%)	-0.324	-0.282	0.042 (13%)	-0.327	-0.288	0.039 (12%)	-0.325	-0.284	0.041 (13%)	-0.322	-0.319	0.003 (1%)
45	San Joaquin River near the confluence with the Mokelumne River	W	-1.314	-1.307	0.008 (1%)	-1.223	-1.199	0.023 (2%)	-1.161	-1.146	0.043 (4%)	-1.196	-1.146	0.049 (4%)	-1.206	-1.188	0.018 (1%)	-1.231	-1.212	0.018 (1%)	-1.296	-1.264	0.032 (2%)
		AN	-1.343	-1.332	0.010 (1%)	-1.284	-1.268	0.016 (1%)	-1.255	-1.236	0.018 (1%)	-1.265	-1.219	0.045 (4%)	-1.285	-1.272	0.013 (1%)	-1.306	-1.297	0.010 (1%)	-1.340	-1.331	0.009 (1%)
		BN	-1.376	-1.364	0.012 (1%)	-1.341	-1.316	0.025 (2%)	-1.295	-1.283	0.012 (1%)	-1.321	-1.304	0.016 (1%)	-1.303	-1.297	0.005 (0%)	-1.316	-1.310	0.006 (0%)	-1.333	-1.330	0.003 (0%)
		D	-1.370	-1.365	0.005 (0%)	-1.348	-1.334	0.014 (1%)	-1.331	-1.321	0.010 (1%)	-1.323	-1.315	0.008 (1%)	-1.314	-1.310	0.004 (0%)	-1.328	-1.323	0.005 (0%)	-1.339	-1.336	0.003 (0%)
		C	-1.358	-1.355	0.002 (0%)	-1.351	-1.345	0.005 (0%)	-1.333	-1.329	0.004 (0%)	-1.337	-1.334	0.003 (0%)	-1.341	-1.339	0.002 (0%)	-1.336	-1.335	0.001 (0%)	-1.333	-1.334	0.000 (0%)
94	Old River downstream of the south Delta export facilities	W	-0.962	-0.953	0.009 (1%)	-0.895	-0.849	0.045 (5%)	-0.859	-0.775	0.084 (10%)	-0.873	-0.724	0.149 (17%)	-0.715	-0.706	0.009 (1%)	-0.733	-0.711	0.022 (3%)	-0.917	-0.815	0.102 (11%)
		AN	-0.977	-0.968	0.008 (1%)	-0.922	-0.884	0.038 (4%)	-0.910	-0.870	0.040 (4%)	-0.927	-0.812	0.115 (12%)	-0.821	-0.838	-0.017 (-2%)	-0.818	-0.834	-0.016 (-2%)	-0.963	-0.929	0.034 (4%)
		BN	-1.002	-0.996	0.006 (1%)	-0.956	-0.888	0.068 (7%)	-0.921	-0.889	0.031 (3%)	-0.940	-0.915	0.025 (3%)	-0.844	-0.877	-0.033 (-4%)	-0.843	-0.867	-0.024 (-3%)	-0.932	-0.923	0.009 (1%)
		D	-0.992	-0.987	0.006 (1%)	-0.965	-0.931	0.034 (4%)	-0.936	-0.919	0.017 (2%)	-0.929	-0.912	0.016 (2%)	-0.865	-0.882	-0.017 (-2%)	-0.851	-0.866	-0.014 (-2%)	-0.929	-0.917	0.012 (1%)
		C	-0.950	-0.952	-0.002 (0%)	-0.955	-0.943	0.012 (1%)	-0.916	-0.915	0.001 (0%)	-0.896	-0.905	-0.008 (-1%)	-0.888	-0.897	-0.009 (-1%)	-0.866	-0.878	-0.012 (-1%)	-0.898	-0.898	0.001 (0%)
212	Old River upstream of the south Delta export facilities	W	-0.451	-0.461	-0.010 (-2%)	-0.461	-0.698	-0.237 (-51%)	-0.377	-0.691	-0.314 (-83%)	-0.342	-0.661	-0.319 (-93%)	-0.418	-0.705	-0.288 (-69%)	-0.504	-0.766	-0.262 (-52%)	-0.261	-0.319	-0.058 (-22%)
		AN	-0.481	-0.465	0.016 (3%)	-0.531	-0.718	-0.187 (-35%)	-0.490	-0.678	-0.188 (-38%)	-0.431	-0.773	-0.342 (-79%)	-0.506	-0.767	-0.261 (-52%)	-0.550	-0.807	-0.257 (-47%)	-0.306	-0.348	-0.043 (-14%)
		BN	-0.433	-0.445	-0.012 (-3%)	-0.525	-0.761	-0.236 (-45%)	-0.501	-0.678	-0.177 (-35%)	-0.465	-0.675	-0.210 (-45%)	-0.548	-0.750	-0.202 (-37%)	-0.604	-0.798	-0.194 (-32%)	-0.369	-0.396	-0.027 (-7%)
		D	-0.472	-0.479	-0.008 (-2%)	-0.500	-0.699	-0.199 (-40%)	-0.544	-0.707	-0.163 (-30%)	-0.578	-0.723	-0.145 (-25%)	-0.620	-0.767	-0.147 (-24%)	-0.642	-0.793	-0.151 (-24%)	-0.400	-0.430	-0.030 (-8%)
		C	-0.591	-0.573	0.018 (3%)	-0.554	-0.700	-0.145 (-25%)	-0.596	-0.718	-0.121 (-20%)	-0.691	-0.797	-0.106 (-15%)	-0.735	-0.829	-0.094 (-13%)	-0.731	-0.830	-0.099 (-14%)	-0.473	-0.489	-0.016 (-3%)
365	Delta Cross Channel	W	-0.052	-0.052	0.000 (0%)	-0.050	-0.050	0.000 (0%)	-0.050	-0.049	0.000 (1%)	-0.051	-0.051	0.000 (1%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.058	-0.060	-0.004 (-2%)
		AN	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (1%)	-0.052	-0.052	0.000 (0%)	-0.053	-0.053	0.000 (0%)	-0.059	-0.061	-0.002 (-3%)
		BN	-0.053	-0.053	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.051	-0.051	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.057	-0.059	-0.002 (-3%)
		D	-0.054	-0.054	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.051	-0.052	0.000 (0%)	-0.052	-0.052	0.000 (0%)	-0.058	-0.060	-0.002 (-3%)

*Table **Error! No text of specified style in document.**-4. Median negative channel velocity as simulated by DSM2-HYDRO for the PA (BA Table 5.4-11)*

DSM2 Channel	Location	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
21	San Joaquin River downstream of HOR	W	0.438	0.438	0.000 (0%)	0.365	0.250	-0.115 (-31%)	0.219	0.083	-0.135 (-62%)	0.167	0.063	-0.104 (-63%)	0.234	0.094	-0.141 (-60%)	0.292	0.135	-0.156 (-54%)	0.385	0.323	-0.063 (-16%)
		AN	0.469	0.458	-0.010 (-2%)	0.438	0.406	-0.031 (-7%)	0.406	0.333	-0.073 (-18%)	0.396	0.260	-0.135 (-34%)	0.396	0.292	-0.104 (-26%)	0.406	0.323	-0.083 (-21%)	0.448	0.438	-0.010 (-2%)
		BN	0.469	0.469	0.000 (0%)	0.458	0.427	-0.031 (-7%)	0.438	0.396	-0.042 (-10%)	0.438	0.396	-0.042 (-10%)	0.427	0.385	-0.042 (-10%)	0.438	0.396	-0.042 (-10%)	0.458	0.458	0.000 (0%)
		D	0.469	0.469	0.000 (0%)	0.458	0.438	-0.021 (-5%)	0.458	0.427	-0.031 (-7%)	0.458	0.438	-0.021 (-5%)	0.448	0.417	-0.031 (-7%)	0.448	0.427	-0.021 (-5%)	0.469	0.458	-0.010 (-2%)
		C	0.469	0.469	0.000 (0%)	0.469	0.448	-0.021 (-4%)	0.458	0.438	-0.021 (-5%)	0.458	0.448	-0.010 (-2%)	0.458	0.448	-0.010 (-2%)	0.458	0.448	-0.010 (-2%)	0.469	0.469	0.000 (0%)
45	San Joaquin River near the confluence with the Mokelumne River	W	0.479	0.479	0.000 (0%)	0.458	0.448	-0.010 (-2%)	0.448	0.438	-0.010 (-2%)	0.448	0.438	-0.010 (-2%)	0.448	0.438	-0.010 (-2%)	0.448	0.448	0.000 (0%)	0.469	0.469	0.000 (0%)
		AN	0.490	0.490	0.000 (0%)	0.469	0.469	0.000 (0%)	0.458	0.448	-0.010 (-2%)	0.458	0.448	-0.010 (-2%)	0.458	0.458	0.000 (0%)	0.469	0.469	0.000 (0%)	0.479	0.479	0.000 (0%)
		BN	0.500	0.490	-0.010 (-2%)	0.490	0.479	-0.010 (-2%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)	0.469	0.469	0.000 (0%)	0.479	0.469	-0.010 (-2%)	0.479	0.479	0.000 (0%)
		D	0.500	0.490	-0.010 (-2%)	0.490	0.479	-0.010 (-2%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)	0.469	0.469	0.000 (0%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)
		C	0.490	0.490	0.000 (0%)	0.490	0.490	0.000 (0%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)	0.479	0.479	0.000 (0%)
94	Old River downstream of the south Delta export facilities	W	0.583	0.573	-0.010 (-2%)	0.531	0.490	-0.042 (-8%)	0.531	0.448	-0.083 (-16%)	0.531	0.438	-0.094 (-18%)	0.448	0.438	-0.010 (-2%)	0.458	0.448	-0.010 (-2%)	0.531	0.479	-0.052 (-10%)
		AN	0.583	0.583	0.000 (0%)	0.531	0.510	-0.021 (-4%)	0.531	0.500	-0.031 (-6%)	0.542	0.469	-0.073 (-13%)	0.469	0.469	0.000 (0%)	0.469	0.469	0.000 (0%)	0.542	0.521	-0.021 (-4%)
		BN	0.667	0.604	-0.063 (-9%)	0.552	0.490	-0.063 (-11%)	0.521	0.521	0.000 (0%)	0.542	0.531	-0.010 (-2%)	0.479	0.490	0.010 (2%)	0.479	0.490	0.010 (2%)	0.531	0.521	-0.010 (-2%)
		D	0.594	0.583	-0.010 (-2%)	0.552	0.531	-0.021 (-4%)	0.531	0.531	0.000 (0%)	0.521	0.521	0.000 (0%)	0.490	0.500	0.010 (2%)	0.490	0.490	0.000 (0%)	0.521	0.510	-0.010 (-2%)
		C	0.542	0.542	0.000 (0%)	0.552	0.552	0.000 (0%)	0.521	0.521	0.000 (0%)	0.500	0.500	0.000 (0%)	0.490	0.490	0.000 (0%)	0.490	0.490	0.000 (0%)	0.490	0.490	0.000 (0%)
212	Old River upstream of the south Delta export facilities	W	0.344	0.354	0.010 (3%)	0.292	0.396	0.104 (36%)	0.125	0.354	0.229 (183%)	0.094	0.297	0.203 (217%)	0.177	0.365	0.188 (106%)	0.229	0.396	0.167 (73%)	0.188	0.385	0.198 (106%)
		AN	0.344	0.365	0.021 (6%)	0.365	0.427	0.063 (17%)	0.313	0.406	0.094 (30%)	0.271	0.417	0.146 (54%)	0.344	0.427	0.083 (24%)	0.365	0.438	0.073 (20%)	0.438	0.464	0.026 (6%)
		BN	0.333	0.365	0.031 (9%)	0.385	0.448	0.063 (16%)	0.365	0.427	0.063 (17%)	0.354	0.438	0.083 (24%)	0.375	0.438	0.063 (17%)	0.396	0.448	0.052 (13%)	0.469	0.490	0.021 (4%)
		D	0.375	0.375	0.000 (0%)	0.385	0.448	0.063 (16%)	0.385	0.448	0.063 (16%)	0.396	0.448	0.052 (13%)	0.406	0.448	0.042 (10%)	0.417	0.458	0.042 (10%)	0.479	0.500	0.021 (4%)
		C	0.396	0.406	0.010 (3%)	0.406	0.458	0.052 (13%)	0.396	0.448	0.052 (13%)	0.438	0.469	0.031 (7%)	0.438	0.469	0.031 (7%)	0.438	0.469	0.031 (7%)	0.500	0.500	0.000 (0%)
365	Delta Cross Channel	W	0.448	0.448	0.000 (0%)	0.427	0.427	0.000 (0%)	0.427	0.417	-0.010 (-2%)	0.427	0.427	0.000 (0%)	0.438	0.427	-0.010 (-2%)	0.427	0.427	0.000 (0%)	0.073	0.083	0.010 (14%)
		AN	0.458	0.458	0.000	0.448	0.448	0.000	0.438	0.438	0.000	0.438	0.438	0.000	0.448	0.448	0.000	0.458	0.458	0.000	0.031	0.063	0.031

DSM2 Channel	Location	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
365	Delta Cross Channel	BN	0.458	0.448	-0.010 (-2%)	0.469	0.458	-0.010 (-2%)	0.458	0.458	0.000 (0%)	0.458	0.458	0.000 (0%)	0.458	0.458	0.000 (0%)	0.469	0.458	-0.010 (-2%)	0.042	0.063	0.021 (50%)
		D	0.458	0.458	0.000 (0%)	0.469	0.469	0.000 (0%)	0.458	0.458	0.000 (0%)	0.458	0.458	0.000 (0%)	0.458	0.458	0.000 (0%)	0.469	0.469	0.000 (0%)	0.042	0.073	0.031 (75%)
		C	0.458	0.458	0.000 (0%)	0.469	0.469	0.000 (0%)	0.469	0.469	0.000 (0%)	0.469	0.469	0.000 (0%)	0.469	0.469	0.000 (0%)	0.469	0.469	0.000 (0%)	0.146	0.156	0.010 (7%)
379	Sutter Slough	W	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)
		AN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.083	0.063	-0.021 (-25%)
		BN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.052	0.063	0.010 (20%)	0.104	0.083	-0.021 (-20%)
		D	0.000	0.063	0.063 (Inf.)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.052	0.052	0.000 (0%)	0.104	0.104	0.000 (0%)
		C	0.167	0.203	0.036 (22%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.021	0.021 (Inf.)	0.083	0.094	0.010 (13%)	0.167	0.188	0.021 (12%)	0.240	0.250	0.010 (4%)
383	Steamboat Slough	W	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.198	0.302	0.104 (53%)
		AN	0.125	0.167	0.042 (33%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.031	0.031 (Inf.)	0.188	0.229	0.042 (22%)	0.302	0.333	0.031 (10%)
		BN	0.167	0.229	0.063 (37%)	0.115	0.146	0.031 (27%)	0.000	0.094	0.094 (Inf.)	0.042	0.146	0.104 (250%)	0.219	0.250	0.031 (14%)	0.281	0.281	0.000 (0%)	0.313	0.313	0.000 (0%)
		D	0.260	0.281	0.021 (8%)	0.182	0.224	0.042 (23%)	0.021	0.125	0.104 (500%)	0.000	0.125	0.125 (Inf.)	0.224	0.229	0.005 (2%)	0.271	0.271	0.000 (0%)	0.313	0.323	0.010 (3%)
		C	0.333	0.344	0.010 (3%)	0.219	0.250	0.031 (14%)	0.146	0.214	0.068 (46%)	0.281	0.292	0.010 (4%)	0.302	0.302	0.000 (0%)	0.344	0.354	0.010 (3%)	0.375	0.375	0.000 (0%)
418	Sacramento River downstream of proposed NDD	W	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)
		AN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)
		BN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.031	0.052	0.021 (67%)	0.000	0.000	0.000 (0%)
		D	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.021	0.042	0.021 (100%)	0.000	0.000	0.000 (0%)
		C	0.141	0.156	0.016 (11%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.005	0.005 (Inf.)	0.073	0.083	0.010 (14%)	0.156	0.167	0.010 (7%)	0.130	0.135	0.005 (4%)
421	Sacramento River upstream of Georgiana Slough	W	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)
		AN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.031	0.031 (Inf.)	0.000	0.000	0.000 (0%)
		BN	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.042	0.073	0.031 (75%)	0.000	0.000	0.000 (0%)
		D	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.021	0.073	0.052 (250%)	0.000	0.000	0.000 (0%)
		C	0.135	0.156	0.021 (15%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.052	0.052 (Inf.)	0.083	0.104	0.021 (25%)	0.167	0.167	0.000 (0%)	0.125	0.135	0.010 (8%)
423	Sacramento River downstream of Georgiana	W	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.281	0.333	0.052 (19%)
		AN	0.146	0.188	0.042 (29%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.000	0.000 (0%)	0.000	0.063	0.063 (Inf.)	0.208	0.250	0.042 (20%)	0.344	0.365	0.021 (6%)

DSM2 Channel	Location	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
	Slough	BN	0.188	0.250	0.063 (33%)	0.135	0.167	0.031 (23%)	0.000	0.115	0.115 (Inf.)	0.083	0.177	0.094 (113%)	0.240	0.250	0.010 (4%)	0.292	0.292	0.000 (0%)	0.354	0.354	0.000 (0%)
		D	0.281	0.302	0.021 (7%)	0.198	0.240	0.042 (21%)	0.083	0.146	0.063 (75%)	0.000	0.146	0.146 (Inf.)	0.229	0.240	0.010 (5%)	0.281	0.281	0.000 (0%)	0.354	0.365	0.010 (3%)
		C	0.344	0.354	0.010 (3%)	0.240	0.260	0.021 (9%)	0.177	0.229	0.052 (29%)	0.292	0.292	0.000 (0%)	0.302	0.313	0.010 (3%)	0.354	0.354	0.000 (0%)	0.396	0.396	0.000 (0%)

The velocity analysis in the BA and described in section 2.5.1.2.7.1.1 above indicates that water velocities in the north Delta would be lower under the PA. This would increase migratory travel

time and potentially increase the risk of predation for emigrating juvenile salmon (i.e., smolts). In the South Delta, median velocities generally increase under PA (Table 5.4-9), which would decrease migratory travel time and predation risk for smolts migrating through the South Delta. In the Central Delta, there is little difference in magnitude of channel velocity between the NAA and PA for any month or water year type at the DCC, except for June (Table).

Effects of Bypass Rules on Reverse Flows

Flow reversals likely reduce the survival probability of outmigrating smolts by moving them back upstream, increasing their exposure to junctions that lead to migratory routes of lower survival. For example, smolts may enter migratory routes that have increased predation risk or entrainment into the interior Delta. Hydrodynamic analysis conducted by USGS (Perry et al. 2016, in review) provides information on the potential influence of the PA operations on Delta inflow. This analysis includes an evaluation of the NDD bypass rules as written in Table 3.3-2 North Delta Diversion Bypass Flows (Appendix x) to determine the effectiveness of the rules to prevent flow reversals in the Sacramento River at the junction of Georgiana Slough. The complete results and methods used for this analysis are located in Appendix YY (TBD).

As reported in Perry et al. (2016, in review), "Research has shown that the entrainment probability of juvenile Chinook salmon into Georgiana Slough and the Delta Cross Channel is highest during reverse-flow flood tides (Perry et al. 2015). Furthermore, the daily proportion of fish entrained into Georgiana Slough increases with the fraction of the day in a reverse flow condition at the Sacramento River downstream of Georgiana Slough (Perry, 2010). Consequently, diverting water from the Sacramento River could increase the frequency and duration of reverse-flow conditions, thereby increasing the proportion of fish entrained into the interior Delta where survival probabilities are lower than in the Sacramento River (Perry and others, 2010, 2013). To accommodate adaptive levels of protection, the NDD bypass rules prescribe a series of minimum allowable bypass flows that vary depending on 1) month of the year and 2) progressively decreasing levels of protection following a pulse flow event."

The likelihood of entering migratory routes with reduced survival may be informed by the daily probability of flow reversal, or as a proportion of each day with reverse flows. The USGS hydrodynamic analysis estimated the frequency and duration of reverse-flow conditions of the Sacramento River downstream of Georgiana Slough under each of the prescribed minimum bypass flows described in the NDD bypass rules Table 3.3-2. The analysis uses historical flow data to estimate the effect of Sacramento River discharge at Freeport (USGS gage 11447650) on two hydrodynamic conditions:

      1) the daily probability of a flow reversal and

      2) the daily proportion of each day with reverse flow.
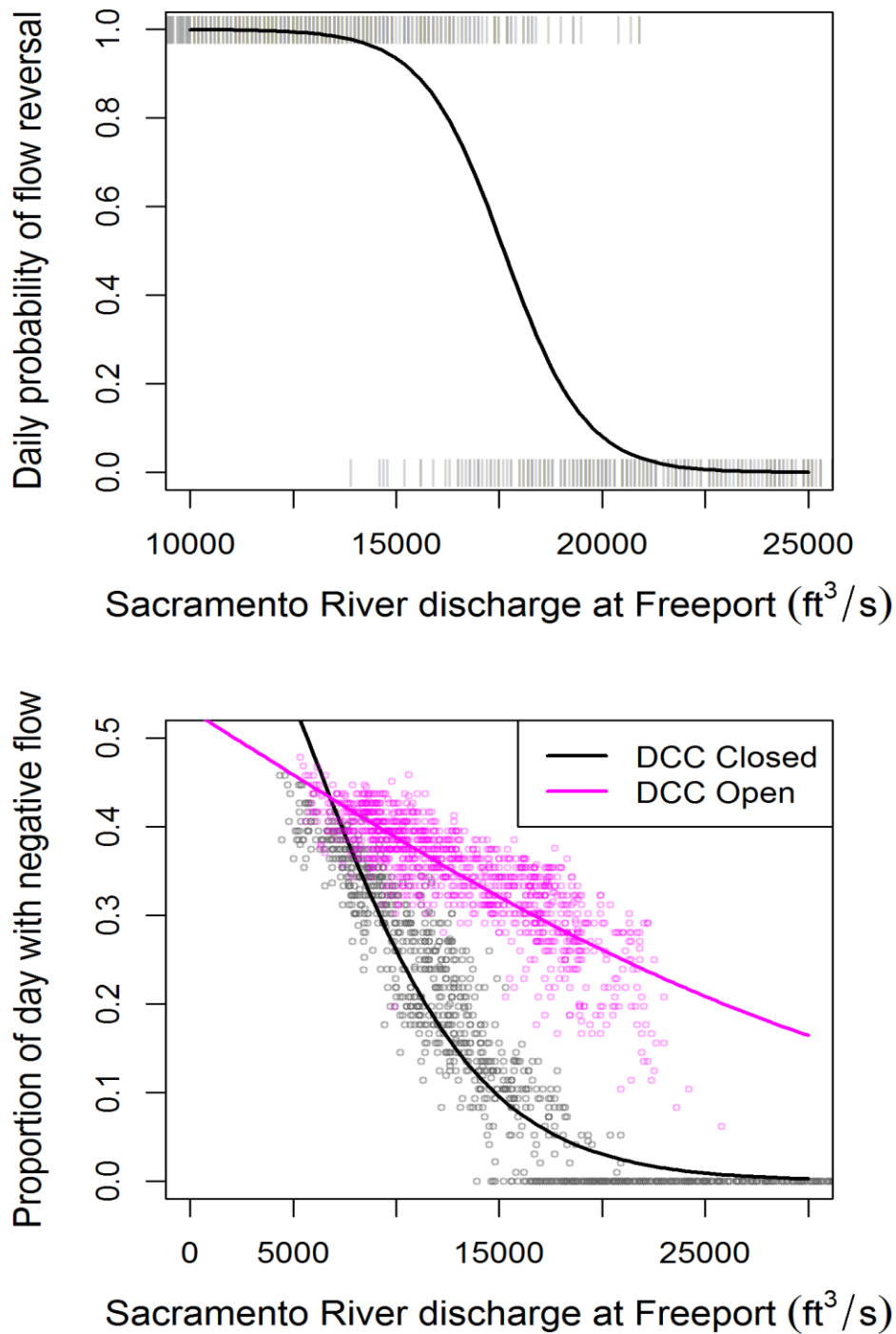
Figure **Error! No text of specified style in document.**-1. Effect of discharge at Freeport on frequency and duration of flow reversals (Figure abc)

Top panel shows the effect of the mean daily discharge (cfs; cubic feet per second) at Freeport on the probability of a flow reversal occurring on a given day at the USGS gage in the

Sacramento River just downstream of Georgiana Slough with the Delta Cross Channel (DCC) gate closed. The bottom panel shows the fraction of each day with reversing flow as a function of DCC gate position and mean daily discharge at Freeport.

The probability of a flow reversal occurring at some time during a 24-hour period is one hundred percent for Freeport flows less than 13,000 cfs (Figure **Error! No text of specified style in document.**-1). Likewise, when flows are greater than 23,000 cfs, reverse flows are not expected to occur at the Georgiana Slough junction. For the range of flows between 13,000 and 23,000 cfs, reverse flows can be expected to occur, but the probability decreases with increasing Freeport flow.

The proportion of day with negative (that is, reverse) flow is approximately 45 percent at a Freeport discharge of about 6,000 cfs regardless of the DCC gate position (bottom panel, Figure **Error! No text of specified style in document.**-1). As Freeport discharge increases over 6,000 cfs, however, the percentage of the day with reverse flows decreases much more sharply with the DCC closed relative to open.

The criteria for the NDD bypass rules include a commitment that the amount of flow withdrawn at the NDD cannot exacerbate reverse flows (i.e., increase the frequency, magnitude, or duration of negative velocities) at the Georgiana Slough junction from December through June. Perry et al. (2016) examines the potential to meet this objective.

The relationships illustrated in Figure **Error! No text of specified style in document.**-1 were used to calculate the change in the probability of a flow reversal and the proportion of the day with reverse flow under each of the prescribed bypass flows described in Table 3.3-2. This hydrodynamic analysis makes the following assumptions to evaluate the PA operations: 1) the NDD bypass rules are applied based on mean daily Sacramento River discharge at Freeport, and 2) water is diverted at a constant rate over an entire day such that the bypass flow is constant over the day. The analysis adheres to a strict interpretation of the NDD bypass rules and does not include flow variations at sub-daily timescales that may be implemented in real-time operations in response to in-situ tidal conditions to prevent reverse flows.

The analysis applies the NDD bypass rules to a Freeport discharge range of 5,000 to 35,000 cfs, which brackets empirical flows covering the full range of reverse flow probabilities (i.e., 0 to 100 percent probability of reverse flow). The analysis compared the probability of flow reversal and the proportion of the day with flow reversals assuming no diversion and diversion under the NDD bypass rules with the DCC closed. The results of this comparison show the magnitude of increase in the frequency and duration of reverse flows due to the PA's NDD bypass rules.

Results are separated into time periods corresponding to NDD bypass rule operations:

1. Constant low-level pumping (pulse protection for December-June)
2. October–November bypass rules
3. Level 1, 2, and 3 post-pulse operations for December-April
4. Level 1, 2, and 3 post-pulse operations for May
5. Level 1, 2, and 3 post-pulse operations for June
6. July–September bypass rules

Applying the NDD bypass rules—as implemented according to the assumptions of the Perry et al (2016) analysis—increases the frequency and duration of reverse flows of the Sacramento River downstream of Georgiana Slough. The magnitude of increase varies depending on the operational time period (e.g., December-June constant low-level pumping; Level 1, 2, and 3 post-pulse operations for December-April; etc.). The most protective bypass rule, constant low-level pumping during December-June, has the smallest increase in probability of and duration of flow reversals (Figure 0-2 and Figure 0-4). October-November operations can increase the probability of reverse flow by more than ten percentage points (Figure 0-5).

For December through June, the months to which post-pulse bypass rules govern the NDD operational level, Level 1 always results in the least increase in the probability of flow reversal (30 to 50 percent probability), while Level 3 results in the greatest increase in probability of flow reversal (100 percent probability). For all of these months, the peak increase in probability occurs in the range of 15,000-25,000 cfs flow at Freeport (Figure 0-2 through 0-4).

The December-April bypass flow rules were developed with the intent to be the most protective of bypass flows to best protect the majority of juvenile winter-run Chinook salmon outmigration. The December-April rules (Figure 0-2) contribute to that objective by producing a lower probability of increased reverse flows than the rules for May and June (Figure 0-3 and Figure 0-4).

For example, the increase in probability of flow reversal at Level 2 pumping for December-April peaks at approximately 0.8 (Figure 0-2), while for May it peaks at 0.9 (Figure 0-3). Even at Level 2 pumping for these more protective December-April constraints, however, the proportion of the day during which reverse flow conditions exist can increase by up to 0.05, or an additional 5 percent of the day, and the probability of reverse flow conditions occurring increases by 80 percent (Figure 0-2).

Similar results, though with greater degrees of change, result for May (Figure 0-3) and June (Figure 0-4). July through November (Figures 0-5 and 0-6) show similarly high increases in probability of flow reversals and proportion of day that reverse flow conditions exist. These months are not governed by the different levels (i.e., pulse protections) that apply to December through June, but instead have static bypass flow requirements.

The USGS hydrodynamic analysis informs how actual diversions often may not be equivalent to allowable diversions as dictated by a strict interpretation of the NDD bypass rules with no other constraints. Given that the USGS analysis shows increases in reverse flows for Level 2 and Level 3 operations, in practice, the Level 2 and Level 3 diversions permitted by the rules would at times be reduced to adhere to the operational commitment of not increasing the frequency, magnitude, and duration of reverse flows in the Sacramento River. Therefore the NDD bypass rules as interpreted strictly without consideration of other operational constraints are not the most accurate representation of the amount of water that could be diverted (i.e., total exports) or the bypass flow that would remain after diversions. However, the analysis does represent a suitable worst-case scenario in regards to adaptive management if the NDD bypass rules, as written, were strictly implemented. This analysis also accurately defines exports and bypass flows when diversions are operating to Level 2 and 3, sweeping criteria are being met and there is no incidence of reverse flow.

DSM2 modeling completed for analysis of PA operations does include constraints to diversion at the north Delta intakes imposed by other requirements such as positive sweeping velocities and D-1641 water quality and outflow constraints. Therefore, results from the DSM2 modeling are likely a closer approximation of actual allowable diversions. The DSM2 modeling runs are more suited as long-term predictors of how operations would commence, however, and do not capture real-time management that may decrease or increase diversions on any given day. DSM2 modeling also does not attempt to limit increases in negative velocities below the diversion screens or at Sacramento River downstream of Georgiana Slough (USGS gage 11447905).
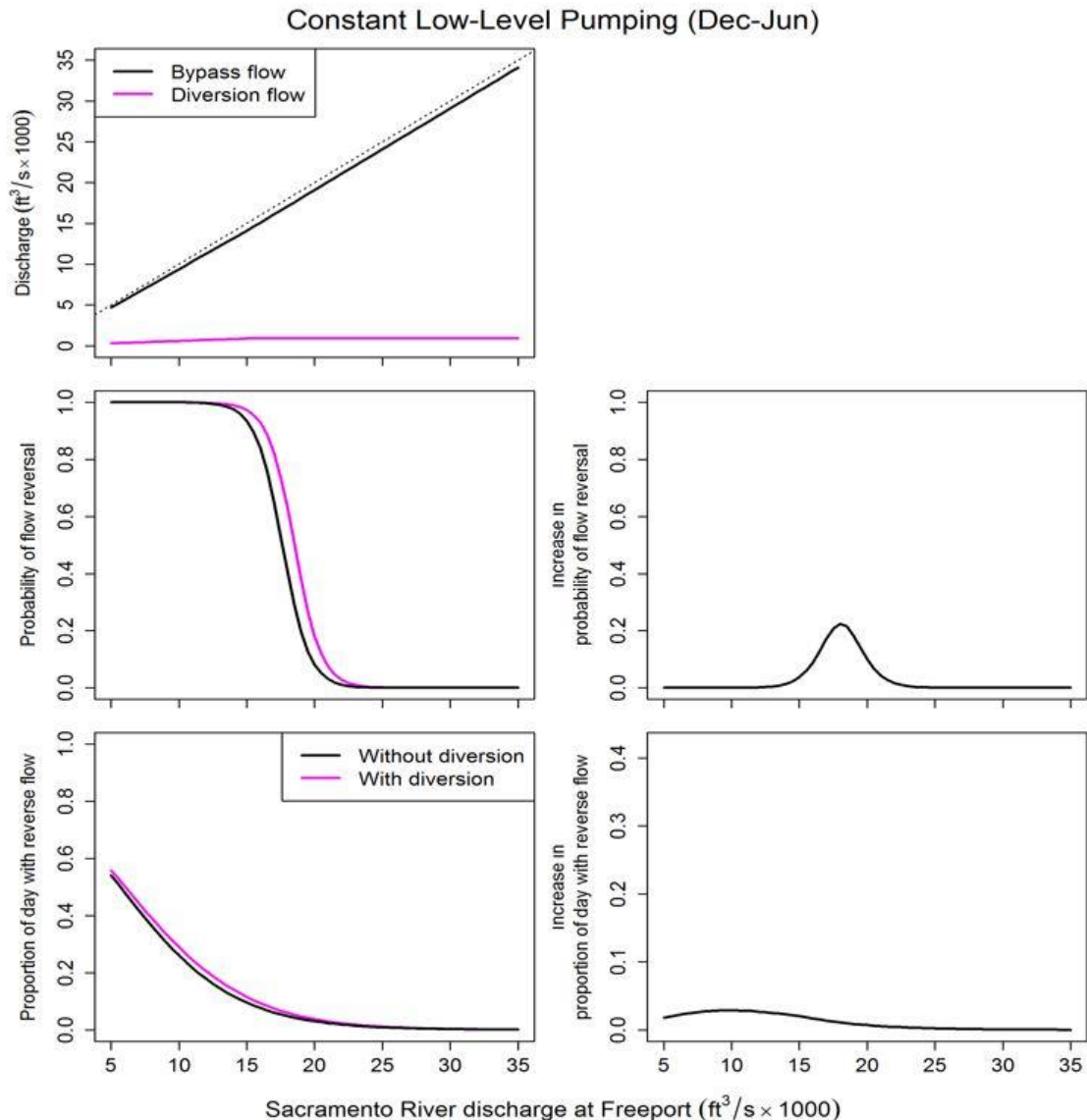
Figure 1. Figure **Error! No text of specified style in document.**-2. Effect of North Delta Diversion (NDD) on bypass discharge, probability of flow reversal, and proportion of the day with reverse flow for constant low-level pumping as defined in the NDD bypass rules. In the top panel, the dotted line shows bypass discharge when diversion discharge is zero.
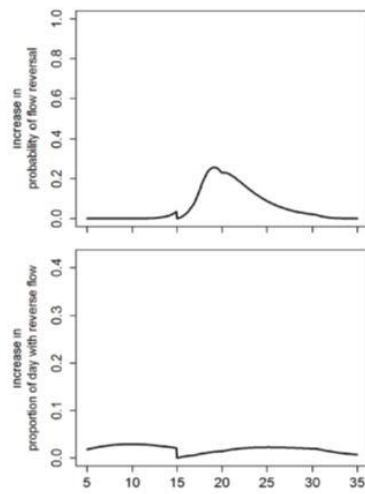
Dec-April Level 1 Bypass Rules
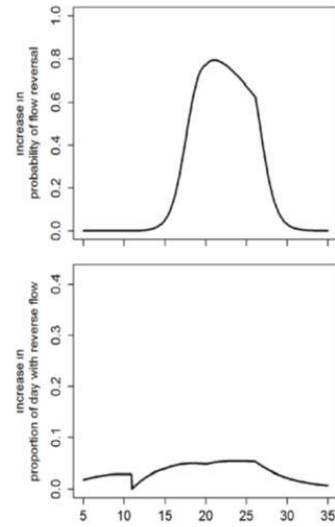
Dec-April Level 2 Bypass Rules
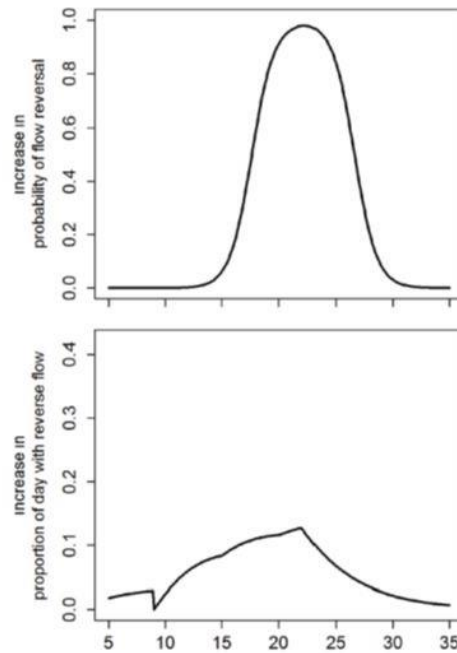
Dec-April Level 3 Bypass Rules

*Figure **Error! No text of specified style in document.**-3. Dec-April Levels 1-3 Bypass Rules*
Sacramento River Discharge at Freeport (ft^3 /s x 1000)
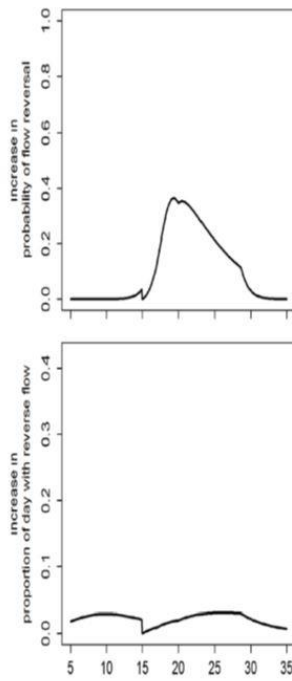
May Level 1 Bypass Rules
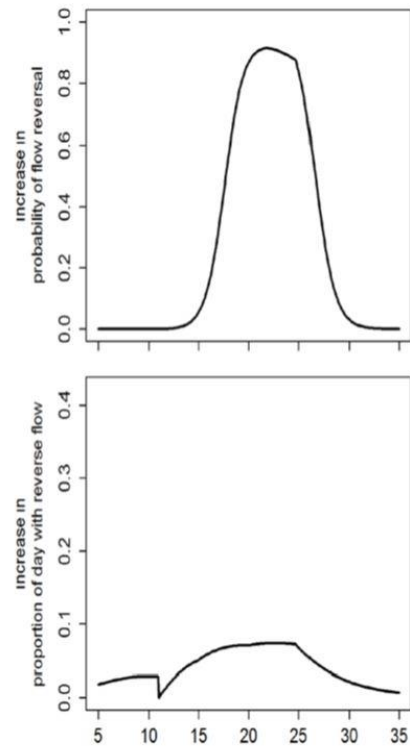
May Level 2 Bypass Rules
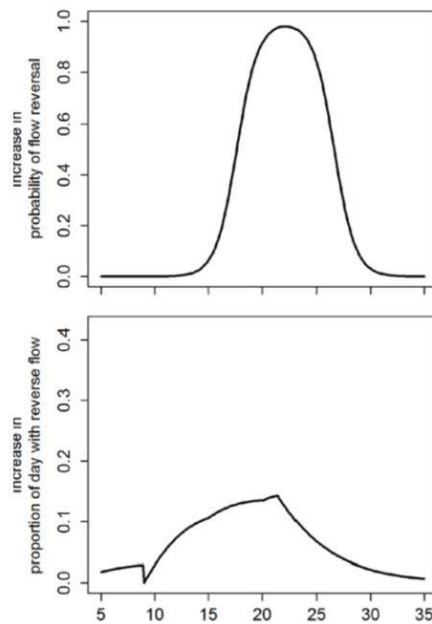
May Level 3 Bypass Rules

Figure 2. Figure **Error! No text of specified style in document.**-4. May Levels 1-3 Bypass Rules

Sacramento River Discharge at Freeport (ft^3 /s x 1000)
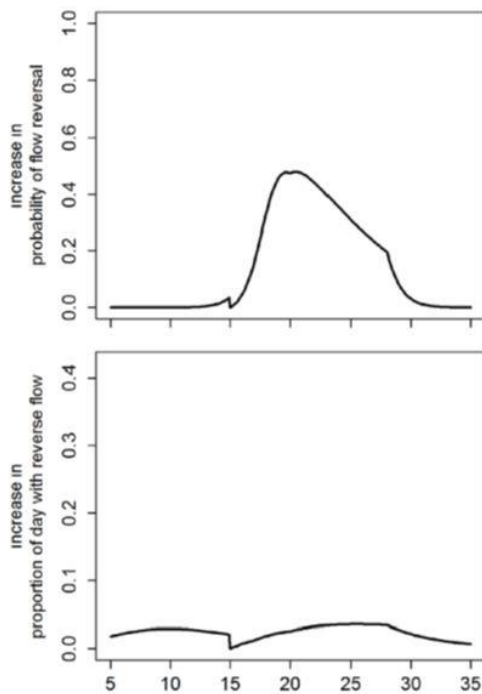
June Level 1 Bypass Rules
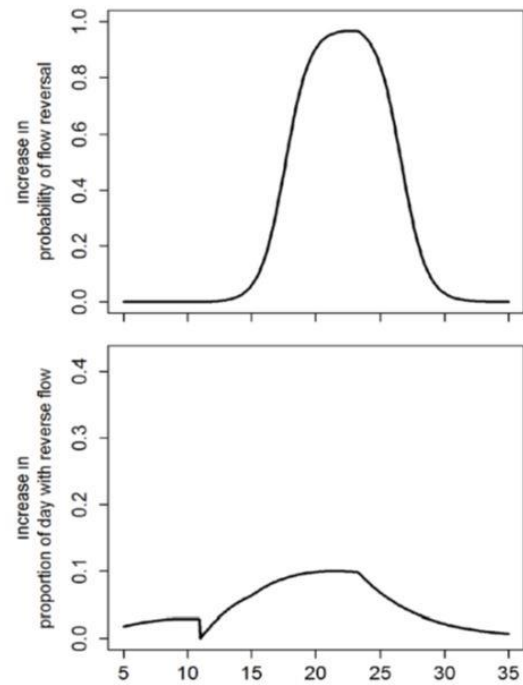
June Level 2 Bypass Rules
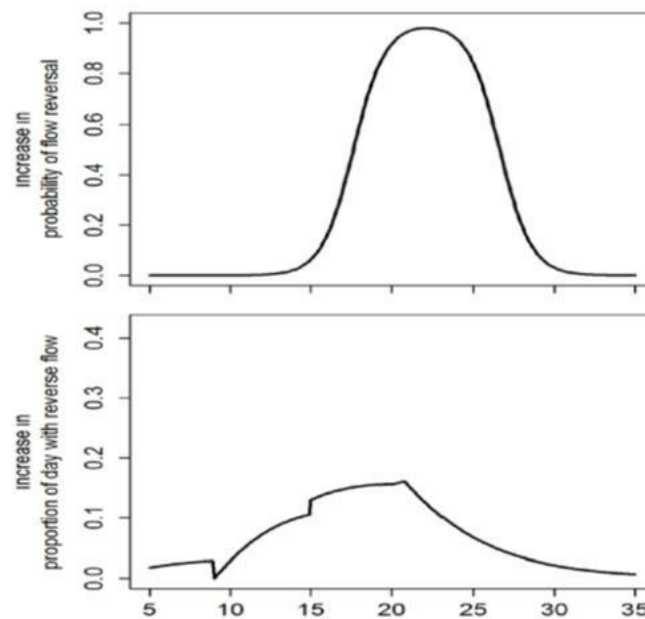
Figure 3. Figure **Error! No text of specified style in document.**-5. June Levels 1-3 Bypass Rules

Sacramento River Discharge at Freeport (ft^3 /s x 1000)
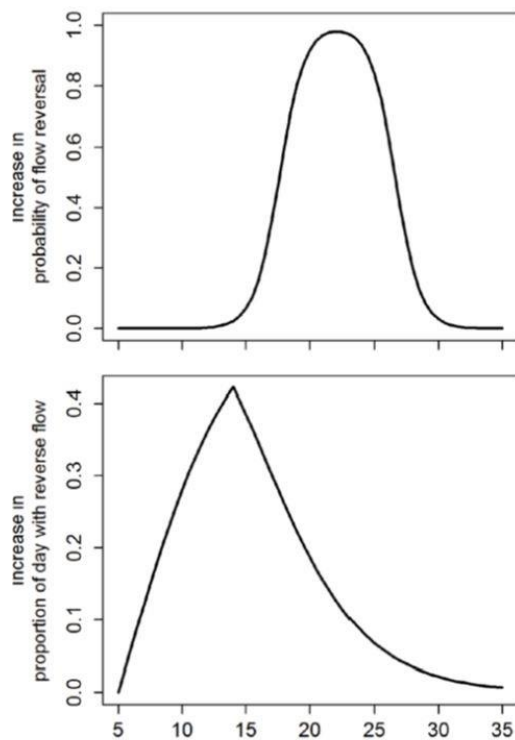
*Figure **Error! No text of specified style in document.**-6. Jul-Sept Bypass Rules*
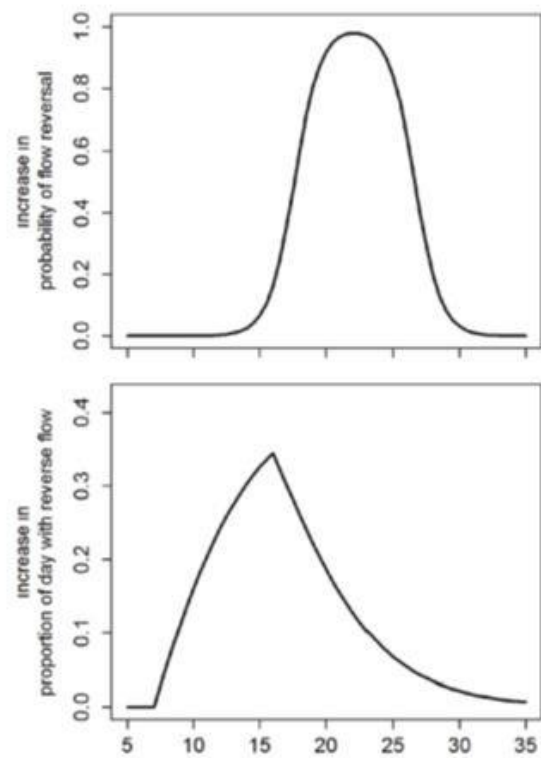
*Figure **Error! No text of specified style in document.**-7. Oct-Nov Bypass Rules*

Sacramento River Discharge at Freeport (ft^3 /s x 1000)

2.5.1.2.7.1.2   Winter-Run Exposure and Risk

Detailed spatial and temporal occurrence of winter-run Chinook salmon presence in the action area has been previously described in *Section 2.5.1.1.1 Acoustic Stress*. Here we present information specific to the area of the NDD intake locations that better informs species exposure and risk to effects of the proposed NDD intake operations.

Winter-run Chinook salmon juvenile entrance into the Delta begins as early as October and extends through April. The majority of juveniles enter the Delta as immature smolt-sized fish (i.e., greater than 70 millimeters fork length (FL)). Studies indicate that winter-run Chinook salmon smolts may spend several weeks and/or months rearing in the lower Sacramento River, the Delta, and associated distributaries before outmigrating to the ocean. The largest proportion of outmigrants enter the Delta in November and December and exit the Delta in March at an average fork length of 111mm (Table 3).

Note: Add discussion of rearing juveniles once fry habitat analysis is complete

Based on sampling from Knights Landing (on the Sacramento River) and the Sacramento Trawl, entrance of winter-run Chinook salmon into the Delta is primarily driven by hydrology. The timing of fall/winter storm pulses that increase Sacramento River flow at Wilkins Slough to 14,000 cfs or greater correspond to observations of large migration events at Knights Landing (del Rosario et al. 2013). This initial migration event has been shown to include over 50 percent of the annual winter-run Chinook salmon population sampled at Knights Landing (del Rosario et al. 2013).

During years with fall or early winter pulse flows, juveniles may enter the Delta or Yolo Bypass at a smaller size (i.e., smaller than 70 millimeters FL). These smaller fish are believed to spend more time rearing in the Delta and floodplain habitats until outmigration to the ocean than their larger migrating counterparts (del Rosario et al 2013). During these early seasonal storm events, winter-run Chinook salmon juveniles are expected to be in the Delta beginning in November or December (Table 3) in significant numbers. Thirty percent of the winter-run-sized smolt population typically is present in these two months (Figure 1-4).

**Wet years migration:
Proportion of winter-run smolts (>70mm)
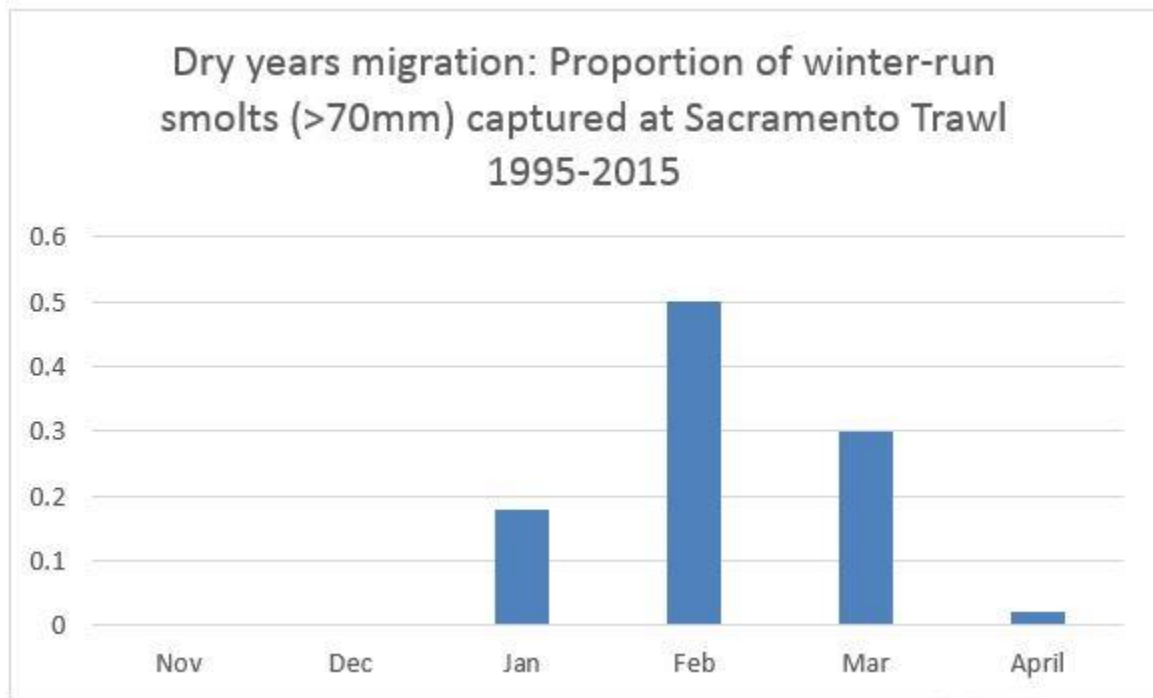captured at Sacramento Trawl 1995-2015**
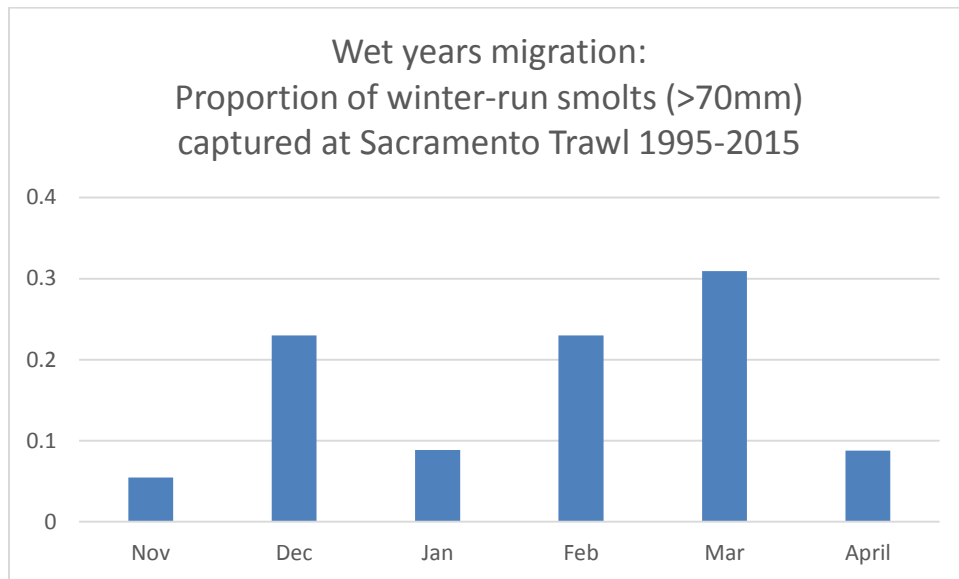
Figure 4. Figure 1-4. Catch of winter run at Sacramento Trawl based on years when a flow pulse upstream (14,000 cfs) occurred after December during wet years.

Juvenile winter-run Chinook migration patterns are different in drier years due to different hydrologic conditions. When late fall/early winter river flows do not approach the 14,000 cfs threshold level, winter-run Chinook salmon rear upstream for several months and are observed further downstream after smaller increases in flow later in the winter. In such drier years, sampling shows that winter-run Chinook salmon juveniles enter the Delta primarily in February (Figure 2-4).

Figure 2-4 Catch of winter run at Sacramento Trawl based on years when a flow pulse upstream (14,000 cfs) occurred after December during dry years.

Table **Error! No text of specified style in document.**-5 shows the proportion of population sampled at Sacramento Trawl and Chipps Island regardless of hydrology or fish size. It becomes evident that November is an important month for fry sized winter-run (less than 70 millimeters) in the Delta. This table encompasses the emigration into and out of the Delta for all winter-run sized fish and is useful for exposure and risk analysis that is not covered in the biological models that focus on smolt-sized migrants (e.g., name models or refer to summary table of models).

*Table **Error! No text of specified style in document.**-5. Winter-run population based on catch per unit effort (cpue) from Midwater Trawl at Chipp's Island, Midwater and Kodiak Trawls at Sherwood Harbor near Sacramento, conducted by The Delta Juvenile Fish Monitoring Program (DJFMP), Stockton, CA USFWS*

Monitoring data years 1995-2015	High >30%		Medium 10-29%		Low 2-9%		Rare/None	
Sacramento Trawl (RM 55) (proportion of population)	Oct (<1%)	Nov (31.7%)	Dec (31.5%)	Jan (7.7%)	Feb (14.4%)	Mar (12%)	Apr (2.7%)	May --
Mean Fork Length (mm) (mean FKL range within years)	--	63 (47-73)	75 (62-99)	93 (77-118)	102 (93-115)	102 (93-110)	--	--
Chipps Island (RM 18) (proportion of population)	Oct --	Nov --	Dec (<1%)	Jan (3.3%)	Feb (14.3%)	Mar (66%)	Apr (15%)	May --
Mean Fork Length (mm) (mean FKL range within years)	--	--	87 (77-95)	107 (92-119)	113 (102-123)	111	117	--

						(103-120)	(107-128)	

Given the information above, the encompassing emigration window for the majority of winter-run Chinook salmon spans from November through April. November and December are peak months for winter-run entry into the Delta at Sacramento; and March is the month of peak presence regardless of hydrology with 66 percent of the sampled winter-run Chinook salmon population exited the Delta in March during the years 1995-2015 (Table 3). In drier years, February is the month of peak entrance into the Delta; 50 percent of the population entered the Delta in February of drier years (Figure 2-4). Overall, November through March are the most important Delta entry and exit months for winter-run Chinook salmon. This includes fry-sized migrants (i.e., smaller than 70 mm FL) which can comprise up to 30 percent of the annual Delta population in November of wet years (Table 3). Note that winter-run juveniles are entering the Delta in Sacramento at fairly large sizes (e.g., mean fork length 63 mm in November and continue to grow until they exit at Chipps Island at mean fork length of 117 m in April; Table 3).

North Delta

The velocity analysis revealed that in the north Delta, the median velocities are reduced under the PA throughout the winter-run Chinook salmon emigration period (December through April) and across all water year types (*Section 2.5.1.2.7.1.1 Channel Velocity Analysis*). Velocities during the month of November were not examined in this analysis. Changes in migratory and habitat conditions in November are examined with other methods and models within this biological opinion (*Section 2.5.1.2.7.2 Effects of Bypass Rules on Riverine Flow*). The reduced velocities in the North Delta suggest outmigrating winter-run smolts will experience longer travel time and, therefore, higher risks to predation during the entirety of their migration period for which velocity data are available.

Specifically, in the North Delta, results for December in below normal, above normal, and wet water year types show that median velocity for the Sacramento River downstream of the DCC, including Steamboat and Sutter Sloughs are 5 to 15 percent lower for the PA (BA Table 5.4-9). December is particularly important for winter-run Chinook in these wetter year types.

During January and February, median velocities are consistently lower by five percent or more under the PA for the Sacramento River downstream of the DCC, including Steamboat and Sutter Slough (BA Table 5.4-9) with the biggest changes occur in January of wet and above normal years ranging from a 10 to 18 percent reduction in velocities. These are important migratory and rearing months for winter-run.

The greatest velocity reductions for the December through April period occur in March where velocities are reduced for the Sacramento River downstream of the DCC, including Steamboat and Sutter Sloughs (BA Table 5.4-9) by 10 percent or more in all water year types except critical years. Velocity reductions in this section of the Delta in March would negatively affect the travel time and increase predation risk of outmigrating smolts during the month of peak abundance of winter-run exiting the Delta.

While the magnitude of velocity reductions in April are not as large as in earlier months, the reductions for PA operations range from 5 to 10 percent for these north Delta locations. This can potentially affect later winter-run Chinook salmon outmigrants, which are an important component of the population diversity.

Central Delta

In the Central Delta at DCC, Dec through April velocities were very similar between the NAA and PA scenarios, which suggests travel time and therefore predation risk for outmigrating smolts in the Central Delta would not change under the PA. Velocities in Georgiana Slough were not examined in this analysis though it is an important migratory route that is examined in other models in this biological opinion.

South Delta

In the South Delta (San Joaquin River downstream of its confluence with Old River and Old River upstream of the south delta pumping facilities), median velocities generally increase for PA operations. In the San Joaquin River, velocities for the PA are often substantially greater in most months, typically by at least 15% and up to 54%, depending on month and water year type. This is mainly due to the presence of the HOR in the PA. Results for Old River downstream of the pumping facilities (DSM2 Channel 94), show a similar level of increase in velocity for the PA in December through March due to reduced south Delta pumping. This is expected to affect the proportion of winter-run juveniles that have entered the interior Delta by reducing risk of entrainment into the South Delta facilities. April (and May) have reduced velocities in Old River downstream of the pumping facilities in the BN to Critical water years. This would mean that winter-run Chinook in the South Delta during April could experience a greater risk of entrainment into the South Delta pumping facilities under the PA (Table 5.4-9)

While these increases in velocity would be expected to decrease the travel time for any outmigrating juvenile salmonids, the San Joaquin River and Old River are not preferred migration routes for winter-run Chinook salmon. Furthermore, only a small portion of the population is expected to benefit from the increased velocity. Acoustic tag studies during 2006 to 2009 showed that approximately 10-35% of outmigrating winter-run Chinook salmon smolts from the Sacramento River entered the interior Delta (Perry et al 2010). Additionally, the small proportion of the population remaining in the Delta after March would not experience velocity increases under the PA since velocities are similar or reduced to the NAA in April.

Overall, increases in velocity in the south Delta locations would reduce travel time risk and entrainment into the South Delta facilities, which would beneficially affect a few winter-run Chinook salmon.

Flow Reversals

An analysis was done to look at changes in differences in the magnitude of negative velocities (flow reversing) between scenarios (Table 5.4-9). During critical years or any periods when the median velocity is negative, there is little difference in median negative velocity between the scenarios (Table 5.4-9) Therefore, in the drier water year types, the PA does not offer a benefit or an adverse effect to juvenile winter-run migrants entering the San Joaquin River from Mokelumne River via DCC or Georgiana Slough (i.e. North and Central Delta). Likewise, when median velocities are negative, the PA does not provide a benefit or adverse effect for winter-run in the Old River downstream of the pumping facilities with the exception of decreased negative velocities (reverse flow) in January and March of wetter water year types (i.e. South Delta). When flow is reversing in north, central or south Delta channels it is generally a negative effect on salmonid migratory success. This analysis indicates that adverse effects of negative velocities are generally not improved under the PA with some minor exceptions (Table 5.4-9).

In the North Delta, increase in flow reversals downstream of Georgiana Slough are of concern for migrating salmonids. Increases in flow reversals would likely reduce the survival probability of outmigrating smolts by moving them back upstream, increasing their exposure to junctions that lead to migratory routes of lower survival, such as in Georgiana Slough. Although reservoir releases would not be made to reduce the occurrence of reverse flow or negative velocities in either scenario, the NDD bypass flow criteria do specify that north Delta diversions cannot increase the frequency, magnitude or duration of reverse flow in the Sacramento River at the Georgiana Slough junction. The results of the modeling, which do not explicitly capture this constraint, may not therefore accurately reflect the results of operations. A similar discussion can be offered for the differences between NAA and PA in the proportion of time each day that velocity was negative in north Delta channels which is the third part of this hydrodynamic analysis in the BA. The modeling results show that the NDD bypass rules do not meet the criteria of not increasing the frequency, duration or magnitude of reverse flows and a real-time monitoring structure will be required to allow adherence to permit criteria.

As noted in the winter-run temporal tables, the entire Delta migration period generally occurs between November and April. As shown in section (xyz) of the written Bypass rules, November would not have a protective Bypass flow under "normal" circumstances and hence subject to reverse flows into migratory routes with reduced survival probabilities. However, if flow in November becomes sufficient through storm runoff events to trigger winter-run emigration towards the Delta, a pulse protection will be enabled that will limit diversions to low level pumping for a certain amount of days or until fish presence is not detected based on predetermined real time management criteria. Without this protection, early emigrating winter-run would be subject to some of the more extreme diversion levels allowed, probability of reverse flows would increase, and face greater risk of entrainment into interior Delta and overall lowered survival.

December and April represent the rest of the winter-run emigration through the Delta. This block of time falls under identical operations rules with Level 1 providing the most protection or least change from the NAA scenario. The increase in probability of a flow reversal remains under 30% and the increase in proportion of day with a flow reversal remains under 5%. Under Level 2, the probability of a flow reversal can be as high as 80% with a ~4-6% increase in proportion of day while under Level 3, the probability of a flow reversal is up to 100% with increase in proportion of day up to 15% (Section 2.5.1.2.7.1.2.Figure 2-2). Another way to describe differences under Level 1 operations compared to Level 2 and 3 is that Level 1 needs the least real time management and comes closest to meeting the prescribed Bypass criteria as actually written. Until a real time flow reversal monitoring plan is in place and tested the most conservative protection would be to remain at Level 1 during winter-run's historic migration window, November through April. Under the proposed action real time monitoring is designed to maximize exports by moving to Level 2 and Level 3 diversion amounts when listed fish are not detected in monitoring sites. Therefore, it is important that a monitoring system is adequate to detect low abundance species if presence is a trigger for operational changes. Statistical analysis on what kind of robust monitoring detection system would be needed to detect movement of individual winter-run into and out of the Delta should be pursued. Using several detection methods such as, flow as a surrogate, historical presence/absence as well as real time sampling would provide a more thorough real time management program to ensure protection during the entire winter-run rearing and out-migration period.

Based on the adverse effects Level 2 and Level 3 diversions have on riverine conditions that influence migration routing, travel time and overall survival, winter-run would be best protected under low level pumping and Level 1 operations. Additionally, if real-time monitoring for detection of migrating winter-run Chinook salmon is used to trigger operation Levels, it must be robust enough to detect low abundance populations and all life history stages. Without assurance that real time monitoring can achieve predetermined success criteria, winter-run and other low abundance species will be at risk of experiencing adverse conditions beyond designated protection levels.

A more thorough look at winter-run survival under the different operating levels by month and water year type is included in the Perry et al 2017 survival model (section xyz). The Perry et al 2017 survival model is best suited to determine overall effects to winter run Chinook due to PA operations in the North Delta. Based on the hydrodynamic analysis in Section 2.5.1.2.7.1.2, Level 1, 2 and 3 operations under the PA indicates that adverse effects of the PA are present throughout the winter-run migratory period with the biggest adverse changes in March, which is the peak month for winter-run Chinook salmon out-migration from the Delta. NMFS therefore expects that the reduction in flow and related increase in travel time in the North Delta would adversely affect a high proportion of outmigrating winter-run Chinook salmon.

2.5.1.2.7.1.3   Spring-Run Exposure and Risk

2.5.1.2.7.1.4   Steelhead Exposure and Risk

2.5.1.2.7.1.5   Green Sturgeon Exposure and Risk

2.5.1.2.7.1.6   Fall/Late Fall-Run Exposure and Risk

2.5.1.2.7.2 Outmigration Routing

Several studies of salmonid migration through the Sacramento-San Joaquin Delta show that the survival rate for salmonids is notably lower for fish that travel through the interior Delta than for those that migrate through the Sacramento River. These reductions are most likely due to higher predation rates in the Delta, longer migration times required to navigate the circuitous path of channels and access Bay waters, and risk of entrainment into the CVP/SWP (Perry et al 2010, Perry et al 2013, Newman et al 2003, Newman and Brandes 2010). Because a large proportion of Sacramento River basin salmon are exposed to interior Delta migration routes, the selection of migration route is considered a stressor that can affect individual survival and population abundance. Assessing survival and migratory changes for Chinook salmon in the Delta with the operations of the PA relies on understanding inflows into and hydrodynamics of the Delta.

2.5.1.2.7.2.1   Flow Routing at Delta Channel Junctions

The BA includes analysis of changes in flow routing at important channel junctions in the Delta (BA section *5.4.1.3.1.2.1.2.1 Flow Routing into Channel Junctions*).

As the BA notes, lower flow in the Sacramento River (as would occur because of exports by the NDD) increases the tidal influence at the Georgiana Slough junction (Perry et al. 2015) and results in a greater proportion of flow (and, presumably, fish) entering into the junction (Cavallo et al. 2015) and into the central Delta. Entry into the central Delta would be an adverse effect to salmonids whereas entry into the distributaries of Sutter and Steamboat Sloughs would be beneficial to salmonids because these are relatively high survival migration pathways that allow fish to avoid entry into the central Delta (Perry et al. 2010; 2012).

NMFS analysis of the flow routing results shows that there is little change in the proportion of flow entering Sutter Slough for the PA versus NAA with the exception of December of critical years, where there is five percent less flow entering Sutter Slough under PA (Table **Error! No text of specified style in document.**-6). At Steamboat Slough, the proportion of flow into the distributary decreased by more than 5% under the PA in some months and water year types such as during February and March of below normal and dry years (Table A below) and January and April of above normal years (BA table 5.4-12). The proportion of flow entering Georgiana Slough for the PA was generally similar to the proportion entering for NAA except for increases in flow proportion into Georgiana Slough in February and March of below normal and dry years (Table 2-1).

Table 5.4-12 Median Daily Proportion of Flow Entering Important Delta Channels, from DSM2-HYDRO Modeling

*Table **Error! No text of specified style in document.**-6. Median Daily Proportion of Flow Entering Important Delta Channels, from DsM2-HYDRO-Modeling*

Table 5.4-12. Median Daily Proportion of Flow Entering Important Delta Channels, from DSM2-HYDRO Modeling, with Green Shading Indicating PA is ≥5% Less than NAA and Red Shading Indicating PA is ≥5% More than NAA (Except for Sutter/Steamboat Sloughs, where Entry is Considered Beneficial and the Color Scheme is Reversed).

Junction	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
Sutter Slough (Entry is beneficial)	W	0.262	0.262	0.000 (0%)	0.264	0.263	-0.001 (0%)	0.267	0.265	-0.002 (-1%)	0.265	0.265	0.000 (0%)	0.263	0.263	0.000 (0%)	0.263	0.263	0.000 (0%)	0.219	0.193	-0.026 (-12%)
	AN	0.259	0.257	-0.002 (-1%)	0.261	0.261	0.000 (0%)	0.263	0.263	0.000 (0%)	0.262	0.263	0.001 (0%)	0.262	0.261	-0.001 (0%)	0.262	0.258	-0.004 (-2%)	0.181	0.174	-0.007 (-4%)
	BN	0.257	0.252	-0.005 (-2%)	0.259	0.258	-0.001 (0%)	0.261	0.261	0.000 (0%)	0.260	0.259	-0.001 (0%)	0.261	0.259	-0.002 (-1%)	0.240	0.238	-0.002 (-1%)	0.175	0.181	0.006 (3%)
	D	0.227	0.219	-0.008 (-4%)	0.256	0.254	-0.002 (-1%)	0.260	0.259	-0.001 (0%)	0.260	0.259	-0.001 (0%)	0.259	0.259	0.000 (0%)	0.242	0.239	-0.003 (-1%)	0.173	0.174	0.001 (1%)
	C	0.195	0.185	-0.010 (-5%)	0.254	0.247	-0.007 (-3%)	0.259	0.256	-0.003 (-1%)	0.249	0.239	-0.010 (-4%)	0.230	0.225	-0.005 (-2%)	0.199	0.195	-0.004 (-2%)	0.151	0.152	0.001 (1%)
Steamboat Slough (Entry is beneficial)	W	0.254	0.242	-0.012 (-5%)	0.278	0.272	-0.006 (-2%)	0.291	0.284	-0.007 (-2%)	0.277	0.270	-0.007 (-3%)	0.257	0.253	-0.004 (-2%)	0.252	0.249	-0.003 (-1%)	0.182	0.180	-0.002 (-1%)
	AN	0.207	0.203	-0.004 (-2%)	0.259	0.248	-0.011 (-4%)	0.279	0.272	-0.007 (-3%)	0.263	0.257	-0.006 (-2%)	0.238	0.229	-0.009 (-4%)	0.202	0.203	0.001 (0%)	0.164	0.169	0.005 (3%)
	BN	0.200	0.193	-0.007 (-4%)	0.213	0.209	-0.004 (-2%)	0.238	0.220	-0.018 (-8%)	0.218	0.205	-0.013 (-6%)	0.196	0.196	0.000 (0%)	0.192	0.194	0.002 (1%)	0.164	0.168	0.004 (2%)
	D	0.192	0.190	-0.002 (-1%)	0.199	0.197	-0.002 (-1%)	0.222	0.210	-0.012 (-5%)	0.232	0.212	-0.020 (-9%)	0.197	0.198	0.001 (1%)	0.192	0.194	0.002 (1%)	0.163	0.169	0.006 (4%)
	C	0.192	0.193	0.001 (1%)	0.198	0.196	-0.002 (-1%)	0.203	0.199	-0.004 (-2%)	0.193	0.194	0.001 (1%)	0.190	0.191	0.001 (1%)	0.191	0.193	0.002 (1%)	0.180	0.183	0.003 (2%)
Delta Cross Channel (Entry is adverse)	W	0.006	0.007	0.001 (17%)	0.004	0.004	0.000 (0%)	0.003	0.003	0.000 (0%)	0.004	0.004	0.000 (0%)	0.005	0.006	0.001 (20%)	0.006	0.006	0.000 (0%)	0.386	0.379	-0.007 (-2%)
	AN	0.009	0.010	0.001 (11%)	0.005	0.006	0.001 (20%)	0.004	0.004	0.000 (0%)	0.005	0.006	0.001 (20%)	0.007	0.008	0.001 (14%)	0.010	0.011	0.001 (10%)	0.432	0.426	-0.006 (-1%)
	BN	0.009	0.010	0.001 (11%)	0.009	0.009	0.000 (0%)	0.007	0.008	0.001 (14%)	0.008	0.009	0.001 (13%)	0.010	0.010	0.000 (0%)	0.011	0.011	0.000 (0%)	0.437	0.430	-0.007 (-2%)
	D	0.011	0.011	0.000 (0%)	0.010	0.010	0.000 (0%)	0.008	0.009	0.001 (13%)	0.008	0.009	0.001 (13%)	0.010	0.010	0.000 (0%)	0.011	0.011	0.000 (0%)	0.442	0.429	-0.013 (-3%)
	C	0.013	0.013	0.000 (0%)	0.010	0.010	0.000 (0%)	0.009	0.010	0.001 (11%)	0.011	0.011	0.000 (0%)	0.011	0.011	0.000 (0%)	0.012	0.013	0.001 (8%)	0.389	0.379	-0.010 (-3%)
Georgiana Slough (Entry is adverse)	W	0.314	0.342	0.028 (9%)	0.293	0.295	0.002 (1%)	0.291	0.292	0.001 (0%)	0.292	0.293	0.001 (0%)	0.302	0.304	0.002 (1%)	0.307	0.311	0.004 (1%)	0.396	0.393	-0.003 (-1%)
	AN	0.395	0.401	0.006 (2%)	0.304	0.327	0.023 (8%)	0.292	0.293	0.001 (0%)	0.299	0.302	0.003 (1%)	0.336	0.360	0.024 (7%)	0.417	0.405	-0.012 (-3%)	0.420	0.402	-0.018 (-4%)
	BN	0.411	0.418	0.007 (2%)	0.396	0.400	0.004 (1%)	0.339	0.379	0.040 (12%)	0.391	0.417	0.026 (7%)	0.424	0.416	-0.008 (-2%)	0.433	0.422	-0.011 (-3%)	0.414	0.412	-0.002 (0%)
	D	0.415	0.419	0.004 (1%)	0.421	0.423	0.002 (0%)	0.382	0.400	0.018 (5%)	0.366	0.406	0.040 (11%)	0.416	0.411	-0.005 (-1%)	0.432	0.423	-0.009 (-2%)	0.415	0.403	-0.012 (-3%)
	C	0.387	0.384	-0.003 (-1%)	0.412	0.428	0.016 (4%)	0.418	0.416	-0.002 (0%)	0.431	0.429	-0.002 (0%)	0.440	0.434	-0.006 (-1%)	0.404	0.397	-0.007 (-2%)	0.363	0.347	-0.016 (-4%)
Head of Old River (Entry is adverse)	W	0.649	0.642	-0.007 (-1%)	0.580	0.322	-0.258 (-44%)	0.537	0.282	-0.255 (-47%)	0.534	0.323	-0.211 (-40%)	0.525	0.259	-0.266 (-51%)	0.527	0.259	-0.268 (-51%)	0.515	0.497	-0.018 (-3%)
	AN	0.663	0.661	-0.002 (0%)	0.616	0.349	-0.267 (-43%)	0.577	0.280	-0.297 (-51%)	0.560	0.264	-0.296 (-53%)	0.529	0.253	-0.276 (-52%)	0.537	0.252	-0.285 (-53%)	0.530	0.474	-0.056 (-11%)
	BN	0.679	0.667	-0.012 (-2%)	0.635	0.342	-0.293 (-46%)	0.602	0.353	-0.249 (-41%)	0.611	0.289	-0.322 (-53%)	0.559	0.264	-0.295 (-53%)	0.581	0.279	-0.302 (-52%)	0.504	0.412	-0.092 (-18%)
	D	0.667	0.662	-0.005 (-1%)	0.647	0.362	-0.285 (-44%)	0.634	0.371	-0.263 (-41%)	0.629	0.385	-0.244 (-39%)	0.597	0.322	-0.275 (-46%)	0.602	0.335	-0.267 (-44%)	0.467	0.377	-0.090 (-19%)

Junction	Water Year Type	December NAA	PA	PA vs. NAA	January NAA	PA	PA vs. NAA	February NAA	PA	PA vs. NAA	March NAA	PA	PA vs. NAA	April NAA	PA	PA vs. NAA	May NAA	PA	PA vs. NAA	June NAA	PA	PA vs. NAA
	C	0.642	0.639	-0.003 (0%)	0.638	0.405	-0.233 (-37%)	0.622	0.383	-0.239 (-38%)	0.594	0.398	-0.196 (-33%)	0.567	0.393	-0.174 (-31%)	0.580	0.383	-0.197 (-34%)	0.367	0.307	-0.060 (-16%)
Turner Cut (Entry is adverse)	W	0.176	0.173	-0.003 (-2%)	0.176	0.181	0.005 (3%)	0.191	0.187	-0.004 (-2%)	0.197	0.190	-0.007 (-4%)	0.180	0.189	0.009 (5%)	0.177	0.187	0.010 (6%)	0.190	0.183	-0.007 (-4%)
	AN	0.171	0.169	-0.002 (-1%)	0.167	0.174	0.007 (4%)	0.175	0.185	0.010 (6%)	0.182	0.185	0.003 (2%)	0.170	0.188	0.018 (11%)	0.167	0.186	0.019 (11%)	0.173	0.173	0.000 (0%)
	BN	0.177	0.172	-0.005 (-3%)	0.165	0.168	0.003 (2%)	0.169	0.181	0.012 (7%)	0.169	0.181	0.012 (7%)	0.164	0.182	0.018 (11%)	0.161	0.176	0.015 (9%)	0.163	0.164	0.001 (1%)
	D	0.168	0.167	-0.001 (-1%)	0.164	0.170	0.006 (4%)	0.161	0.170	0.009 (6%)	0.159	0.168	0.009 (6%)	0.157	0.170	0.013 (8%)	0.157	0.168	0.011 (7%)	0.160	0.160	0.000 (0%)
	C	0.161	0.161	0.000 (0%)	0.161	0.167	0.006 (4%)	0.158	0.166	0.008 (5%)	0.152	0.159	0.007 (5%)	0.150	0.157	0.007 (5%)	0.151	0.158	0.007 (5%)	0.153	0.153	0.000 (0%)
Columbia Cut (Entry is adverse)	W	0.169	0.166	-0.003 (-2%)	0.166	0.163	-0.003 (-2%)	0.171	0.161	-0.010 (-6%)	0.173	0.157	-0.016 (-9%)	0.155	0.157	0.002 (1%)	0.155	0.157	0.002 (1%)	0.169	0.161	-0.008 (-5%)
	AN	0.166	0.164	-0.002 (-1%)	0.161	0.162	0.001 (1%)	0.165	0.165	0.000 (0%)	0.166	0.158	-0.008 (-5%)	0.153	0.160	0.007 (5%)	0.151	0.159	0.008 (5%)	0.164	0.161	-0.003 (-2%)
	BN	0.171	0.167	-0.004 (-2%)	0.160	0.158	-0.002 (-1%)	0.162	0.165	0.003 (2%)	0.161	0.164	0.003 (2%)	0.151	0.160	0.009 (6%)	0.149	0.158	0.009 (6%)	0.157	0.156	-0.001 (-1%)
	D	0.164	0.163	-0.001 (-1%)	0.159	0.161	0.002 (1%)	0.156	0.160	0.004 (3%)	0.153	0.158	0.005 (3%)	0.149	0.156	0.007 (5%)	0.148	0.154	0.006 (4%)	0.154	0.152	-0.002 (-1%)
	C	0.158	0.157	-0.001 (-1%)	0.157	0.160	0.003 (2%)	0.152	0.158	0.006 (4%)	0.147	0.151	0.004 (3%)	0.144	0.148	0.004 (3%)	0.144	0.149	0.005 (3%)	0.147	0.147	0.000 (0%)
Middle River (Entry is adverse)	W	0.189	0.186	-0.003 (-2%)	0.183	0.178	-0.005 (-3%)	0.185	0.174	-0.011 (-6%)	0.184	0.168	-0.016 (-9%)	0.167	0.168	0.001 (1%)	0.169	0.169	0.000 (0%)	0.186	0.176	-0.010 (-5%)
	AN	0.190	0.187	-0.003 (-2%)	0.180	0.178	-0.002 (-1%)	0.182	0.180	-0.002 (-1%)	0.183	0.173	-0.010 (-5%)	0.170	0.175	0.005 (3%)	0.170	0.174	0.004 (2%)	0.183	0.180	-0.003 (-2%)
	BN	0.194	0.189	-0.005 (-3%)	0.182	0.175	-0.007 (-4%)	0.180	0.180	0.000 (0%)	0.181	0.179	-0.002 (-1%)	0.171	0.176	0.005 (3%)	0.170	0.175	0.005 (3%)	0.178	0.177	-0.001 (-1%)
	D	0.188	0.186	-0.002 (-1%)	0.181	0.180	-0.001 (-1%)	0.179	0.178	-0.001 (-1%)	0.177	0.178	0.001 (1%)	0.171	0.175	0.004 (2%)	0.170	0.174	0.004 (2%)	0.176	0.175	-0.001 (-1%)
	C	0.180	0.180	0.000 (0%)	0.179	0.179	0.000 (0%)	0.175	0.176	0.001 (1%)	0.171	0.172	0.001 (1%)	0.169	0.172	0.003 (2%)	0.169	0.172	0.003 (2%)	0.170	0.170	0.000 (0%)
Mouth of Old River (Entry is adverse)	W	0.178	0.174	-0.004 (-2%)	0.177	0.172	-0.005 (-3%)	0.181	0.170	-0.011 (-6%)	0.177	0.164	-0.013 (-7%)	0.162	0.161	-0.001 (-1%)	0.163	0.161	-0.002 (-1%)	0.174	0.167	-0.007 (-4%)
	AN	0.174	0.172	-0.002 (-1%)	0.173	0.171	-0.002 (-1%)	0.175	0.172	-0.003 (-2%)	0.173	0.164	-0.009 (-5%)	0.159	0.162	0.003 (2%)	0.159	0.161	0.002 (1%)	0.171	0.169	-0.002 (-1%)
	BN	0.177	0.173	-0.004 (-2%)	0.168	0.164	-0.004 (-2%)	0.169	0.169	0.000 (0%)	0.165	0.164	-0.001 (-1%)	0.158	0.162	0.004 (3%)	0.158	0.161	0.003 (2%)	0.167	0.167	0.000 (0%)
	D	0.171	0.170	-0.001 (-1%)	0.167	0.166	-0.001 (-1%)	0.165	0.165	0.000 (0%)	0.162	0.163	0.001 (1%)	0.158	0.161	0.003 (2%)	0.158	0.160	0.002 (1%)	0.166	0.164	-0.002 (-1%)
	C	0.166	0.165	-0.001 (-1%)	0.166	0.166	0.000 (0%)	0.163	0.163	0.000 (0%)	0.157	0.159	0.002 (1%)	0.155	0.156	0.001 (1%)	0.156	0.158	0.002 (1%)	0.161	0.161	0.000 (0%)

*Table **Error! No text of specified style in document.**-7. Proportion of flow highlighted in red when over 5% difference between scenarios and is considered an adverse effect*

		February				March		
		NAA	PA	PA vs NAA		NAA	PA	PA vs NAA
Steamboat Slough (less flow is adverse impact to salmonids)	W	0.291	0.284	-0.007 (-2%)	W	0.277	0.270	-0.007 (-3%)
	AN	0.279	0.272	-0.007 (-3%)	AN	0.263	0.257	-0.006 (-2%)
	BN	0.238	0.220	-0.018 (-8%)	BN	0.218	0.205	-0.013 (-6%)
	D	0.222	0.210	-0.012 (-5%)	D	0.232	0.212	-0.020 (-9%)
	C	0.203	0.199	-0.004 (-2%)	C	0.193	0.194	0.001 (1%)
		February				March		
		NAA	PA	PA vs NAA		NAA	PA	PA vs NAA
Georgiana Slough (more flow is adverse impact to salmonids)	W	0.291	0.292	0.001 (0%)		0.292	0.293	0.001 (0%)
	AN	0.292	0.293	0.001 (0%)		0.299	0.302	0.003 (1%)
	BN	0.339	0.379	0.040 (12%)		0.391	0.417	0.026 (7%)
	D	0.382	0.400	0.018 (5%)		0.366	0.406	0.040 (11%)
	C	0.418	0.416	-0.002 (0%)		0.431	0.429	-0.002 (0%)

NMFS' analysis of the flow routing in Table **Error! No text of specified style in document.**-6 shows more flow entering the DCC for the PA in December and February through May. Because the DCC is closed January through May, however, December becomes the primary month of concern. The effects of increased opening of the DCC for the PA operations is analyzed further in the entrainment model (Perry et al. 2016 in review) in section *2.5.1.2.7.2.2 Entrainment of Salmonid Smolts into the Central Delta*.

Therefore in framing the flow routing analysis in the context of the species for the north Delta, the results suggest that juvenile salmonids outmigrating through the Sacramento River would have somewhat greater potential to enter the interior Delta through Georgiana Slough for the operations proposed in the PA. This effect is greater in mid-to-dry water year types.

In the South Delta, at the head of Old River where entry for salmonids is considered adverse, there is a substantial decrease in the amount of flow from the mainstem San Joaquin River entering Old River in January through June in all water year types for the PA due to the HOR gate being in place during key salmonid migratory months (Table **Error! No text of specified style in document.**-6). In December of all water year types, there is less than five percent change between the scenarios.

At Turner Cut, where entry for salmonids is considered adverse, there is a consistent trend of more flow (greater than five percent) entering this distributary for the PA during February

through May (Table **Error! No text of specified style in document.**-6). In December, January, and June there is less than five percent change between scenarios.

At Columbia Cut, where entry for salmonids is considered adverse, the PA increases the proportion of flow entering this distributary in above normal and below normal water year types during April and May and also in April of dry years by more than five percent. In the wet water year types in February, March, and June, the NAA has an increased proportion of flow into Columbia Cut. The changes in flow into Columbia Cut described above are relative changes greater than five percent, but under ten percent. In the other months and water year types, there were no changes greater than five percent between scenarios.

In Middle River and the mouth of Old River, where entry for salmonids is considered adverse, there were a few months in the wetter water year types where flow into these distributaries were lower under the PA specifically. This includes February of wet years and March of wet and above normal years for both junctions, and June of wet years for Middle River.

2.5.1.2.7.2.2   Entrainment of Salmonid Smolts into the Central Delta

The proposed operations of the North Delta Diversions may influence the selection of migratory routes of outmigrating smolts through the Delta. Smolts from the Sacramento River may stay in the mainstem Sacramento River or enter the interior Delta via Georgiana Slough or Delta Cross Channel (DCC). We use the entrainment probability model of Perry et al 2016 (in review) (hereafter "Perry et al. model") to predict the probability of juvenile Chinook salmon 1) remaining in the mainstem Sacramento River, 2) being entrained into Georgiana Slough, or 3) being entrained into the DCC for the operations of the PA and NAA scenarios. The Perry et al. entrainment model uses flows simulated by DSM2-HYDRO from October through June for each water year type over the 82-year modeling period typical of PA analyses (Reclamation 2016).

A complete description of the model, including model equations, estimated parameters, and goodness-of-fit, can be found in Perry et al. (2015) and Perry (2010). Information on the methods and the DSM2 bias correction performed to conduct this analysis can also be found in Perry et al. (2016).

The probabilities of entrainment into Georgiana Slough, DCC, or the mainstem Sacramento River were based on averaging daily entrainment probabilities 1) annually, 2) monthly within water year types, and 3) by run timing distributions. However, the entrainment model was based on data collected at a maximum Freeport discharge of 40,700 cfs, whereas the DSM2 simulations of the PA and NAA scenarios include Freeport flows up to approximately 80,000 cfs. Because the Perry et al. (2015) model appears to over-estimate entrainment at flows greater than 41,000 cfs, the analysis of simulated daily entrainment probabilities was restricted to modeled Freeport flows lower than 41,000 cfs.

Because the timing of smolt outmigration varies by year and is largely influenced by the timing of first pulse flows (del Rosario et al. 2013), the Perry et al. (2015) model predicts the probability of entrainment under three categories of run timing. The three run-timings are 1) a uniform distribution, where an equal proportion of fish outmigrate on each day of the month; 2) an early run timing representing winter-run Chinook salmon smolts in years when flow conditions trigger an early migration into the Delta (i.e., on or before December 31); and 3) a late run timing representing winter-run Chinook salmon smolts in years when flow conditions trigger a later migration into the Delta (i.e., on or after January 1 (Figure **Error! No text of specified style in**

document.-8)). Estimates of annual entrainment probability for the different run timings were calculated as a weighted average of the daily entrainment probability weighted by the proportion of the run migrating on a given day. Run timing distributions were based on winter-run sized (greater than 70 millimeter fork length) juvenile sample data from Sacramento Trawl (Y.Redler, written commun. January 7, 2016).
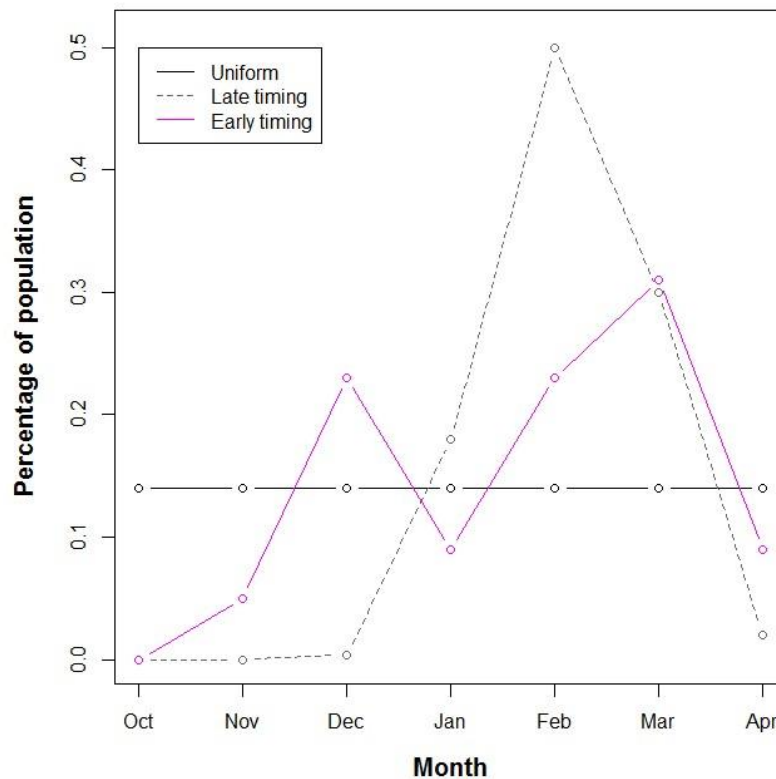
*Figure **Error! No text of specified style in document.**-8. Migration timing scenarios used to estimate mean annual entrainment probabilities, with the early and late timings representing two scenarios for winter-run Chinook salmon in the Sacramento River*

The scenario with a higher percentage of smolts remaining in the Sacramento River reduces the likelihood of smolt entrainment into the lower survival routes of the interior Delta (Georgiana Slough, Delta Cross Channel). For the PA, the mean annual probability of fish remaining in the mainstem Sacramento River is lower regardless of run-timing scenario (Table **Error! No text of specified style in document.**-8). In general, the mean annual entrainment probabilities differ little between NAA and PA; however, there is a consistent trend of greater entrainment into the interior Delta for the PA for all three run timings (Table **Error! No text of specified style in document.**-8). Specifically, entrainment in the DCC is consistently higher for uniform and early run timings (Table **Error! No text of specified style in document.**-8). Entrainment into Georgiana Slough is slightly higher under late and early run timings (Table **Error! No text of specified style in document.**-8). The differences in annual entrainment among the run timing scenarios suggests that daily entrainment probabilities vary seasonally, thereby affecting annual entrainment differentially for the alternative run timings (Figure **Error! No text of specified**

style in document.-9). The probability of entrainment into DCC is notably higher for the PA (Figure **Error! No text of specified style in document.**-9).

*Table **Error! No text of specified style in document.**-8. Mean (SD) predicted annual entrainment probabilities under different run-timing scenarios for NAA and PA simulations conducted with DSM2*

Run-timing	Sacramento River		Georgiana Slough		Delta Cross Channel	
	NAA	PA	NAA	PA	NAA	PA
Uniform	0.571 (0.031)	0.556 (0.028)	0.349 (0.017)	0.346 (0.017)	0.072 (0.03)	0.089 (0.024)
Late	0.555 (0.132)	0.547 (0.129)	0.344 (0.09)	0.352 (0.094)	0 (0)	0 (0)
Early	0.558 (0.085)	0.549 (0.082)	0.346 (0.061)	0.352 (0.063)	0.018 (0.018)	0.021 (0.018)
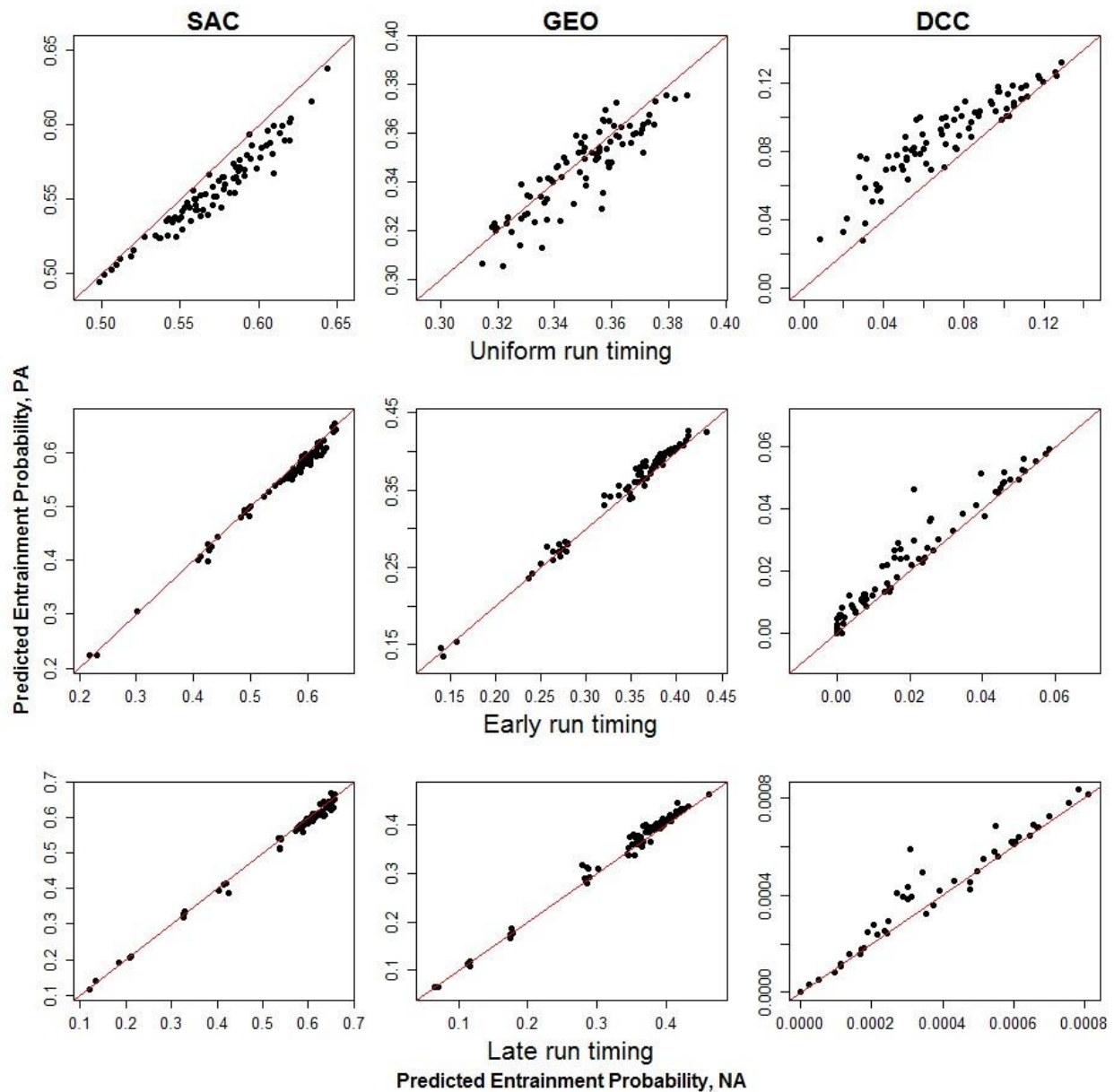
*Figure **Error! No text of specified style in document.**-9. Comparison of predicted mean entrainment probability for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the Proposed Action (PA) and No Action Alternative (NAA) for uniform arrival, and early and late run timing*

For PA operations, the probabilities of smolts remaining in the mainstem Sacramento River during the salmonid migration period are consistently lower across water year types, especially in the months of October, November, December, and occasionally June (Figure **Error! No text of specified style in document.**-9). Entrainment into Georgiana Slough is also higher in October and November (Figure **Error! No text of specified style in document.**-9).

The DCC gates are open more frequently during these months for PA operations, which is the reason for higher probability of entrainment into DCC at these times. DCC operations, as

characterized in both scenarios, requires that the DCC gates remain closed when Sacramento River flow downstream of the NDD intake location is greater than 25,000 cfs. This is required to limit the potential for flooding and scour at the cross channel. For PA operations, water diversion at the DCC reduces bypass flows to levels lower than 25,000 cfs, which allows the DCC gates to remain open at times when they would have otherwise been closed. In turn, opening the Delta Cross Channel gates substantially reduces the instantaneous probability of fish remaining in the Sacramento River by increasing the probability of fish entering the Delta Cross Channel (Figure **Error! No text of specified style in document.**-9).

As Figure **Error! No text of specified style in document.**-9 shows, in wet years, the most notable changes are that fewer fish remain (median ~3-5%) in the Sacramento River for the PA during October, November and June. Smaller changes include fewer fish (median 1%) remaining in the Sacramento River for the PA in December, February and March.

In AN years, fewer fish remain (median 2-4%) in the Sacramento River for the PA during October, November and June and slightly fewer remain (median ~ 1%) in December.

In BN years, fewer fish remain (median ~2-5%) in the Sacramento River for the PA during October, November and March. In December, January, February and June fewer fish (median ~1%) remain in Sacramento River for the PA as well.

In Dry years, October and November show the biggest differences with fewer fish (median~4%) remaining in the Sacramento River for the PA. December, January, February, March and June have fewer fish (median ~ 1%) remaining in the Sacramento River for the PA.

In Critical years, the median entrainment is similar in all months with a probability of fewer fish remaining in the Sacramento River for the PAA during October, November, December and February (median 1 to 2%).

April and May were very similar between the scenarios throughout all water year types with median differences remaining under 1% (Figure **Error! No text of specified style in document.**-9).
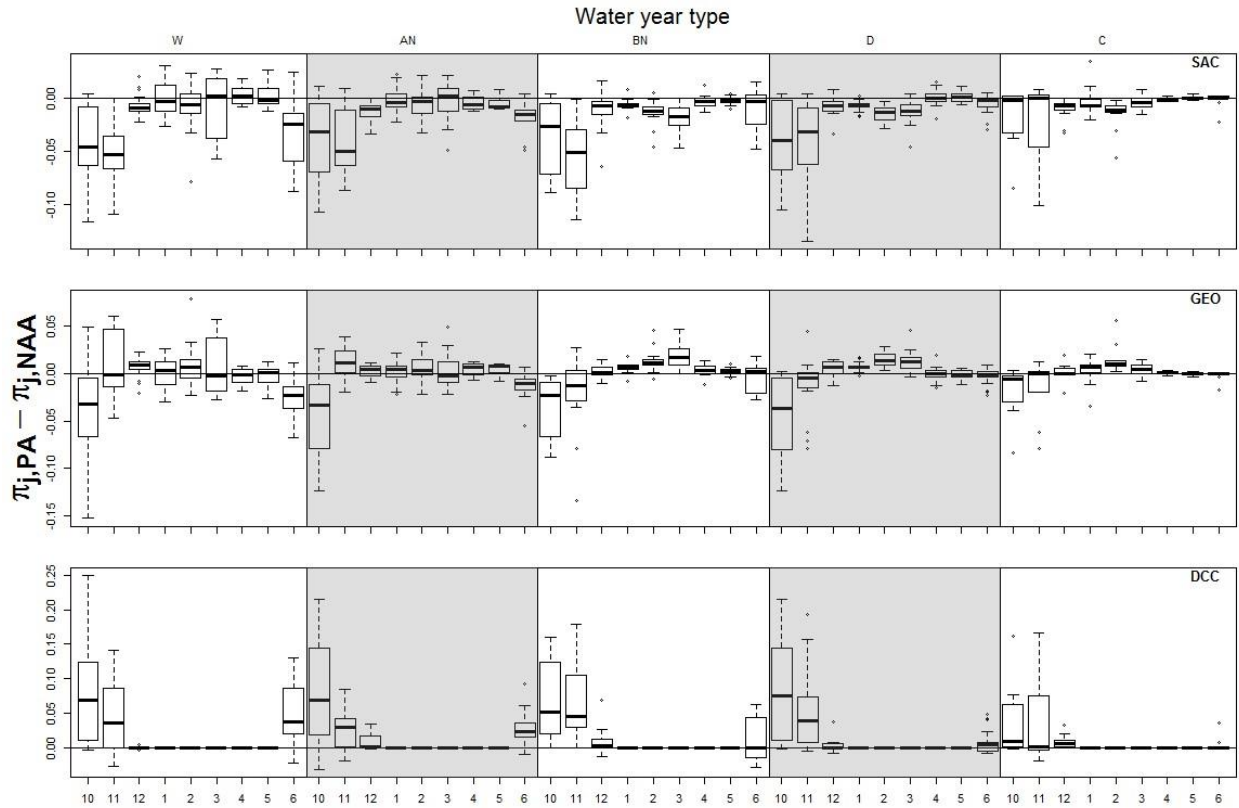
*Figure **Error! No text of specified style in document.**-10. Difference in entrainment probability between Proposed Action (PA) and No Action Alternative (NAA) by water year type and month assuming a uniform run timing (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical) for the Sacramento River (top panel), Georgiana Slough (middle panel), and DCC (bottom panel). π_j is the probability of entrainment into channel j. Y-axis refers to month (1=Jan, 2=Feb, etc.). Boxes range from the 25th to the 75th percentiles with a line indicating the median; whiskers extend 1.5 times past the length of the box, and dots represent data points that fall beyond the whiskers. Entrainment into DCC is possible only when the gate is open during the months of October, November, December, and June.*

Further components of the analysis shows that much of the interannual variation in mean annual entrainment probabilities could be attributed to water year classification. For example, mean annual entrainment probability into the mainstem Sacramento River for the uniform run timing decreased from a median of about 0.60 to 0.52 as water year type transitioned from wet to critically dry years (Figure **Error! No text of specified style in document.**-11 below). Therefore, relative entrainment probabilities into the Interior Delta increases in drier years.
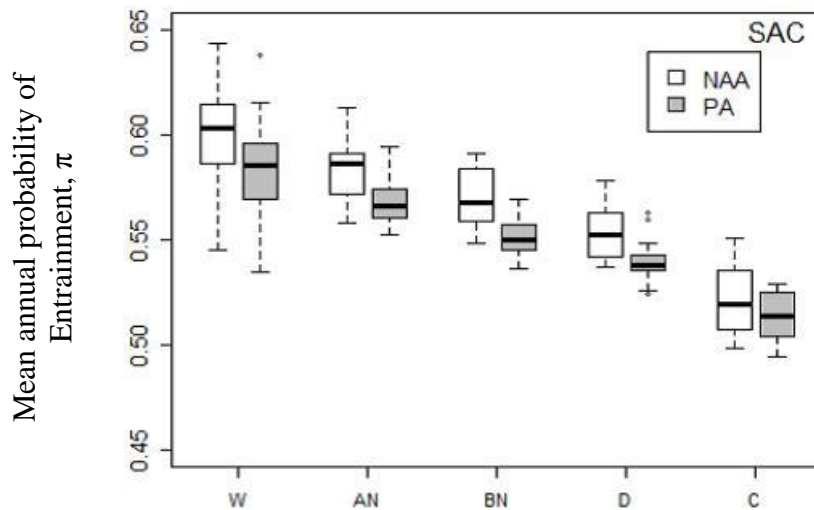
*Figure **Error! No text of specified style in document.**-11. Boxplot of predicted mean annual entrainment probability for the Sacramento River (SAC) between the No Action Alternative (NAA) and Proposed Action (PA) by water year type based on a uniform run-timing distribution (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical)*

For the PA, the median probability of remaining in the Sacramento River was lower under all three run timings and across all water year types (Figure **Error! No text of specified style in document.**-12, top panel). The probability of entrainment into Georgiana Slough in wet years under the uniform run timing is higher under the NAA (Figure **Error! No text of specified style in document.**-12, middle panel). This is due to the DCC, which is located above the Georgiana Slough junction, entraining fish from the Sacramento River for operations of the PA (Figure **Error! No text of specified style in document.**-12, bottom panel) leaving less of a proportion of the population in the Sacramento that could then be entrained into Georgiana Slough.
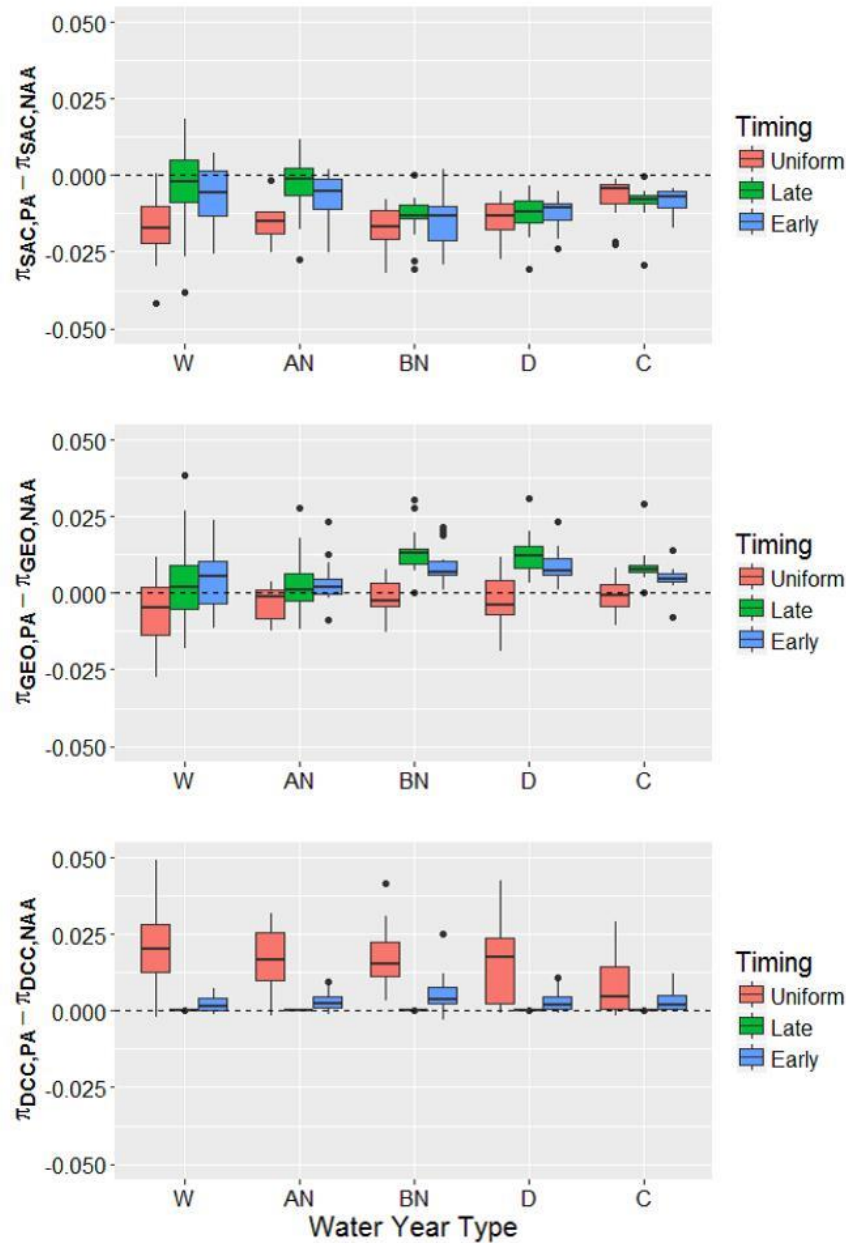
*Figure **Error! No text of specified style in document.**-12. Boxplots of the difference between No Action Alternative (NAA) and Proposed Action (PA) for each route (SAC = Sacramento River, GEO = Georgiana Slough, DCC = Delta Cross Channel) by water year type (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical) and run timing scenario. π_j is the probability of entrainment into channel j. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers extend 1.5 times past the length of the box, and dots represent data points that fall beyond the whiskers*

The analysis of Perry et al. (2012) included evaluation of the sensitivity of overall survival of emigrating juvenile Chinook salmon to changes in entrainment into the interior Delta. Results show that overall survival through the Delta increases between 2-7 percentage points if entrainment into the interior Delta is completely eliminated (assuming no change in route-

specific survival). Applying this information to the above analysis of the PA, the 3-5 percentage point difference between PA and NAA in the probability of being entrained to the interior Delta is expected to contribute relatively little to the change in overall survival. However, reduced inflows to the Delta caused by the operations of the NDD may simultaneously influence both route-specific survival and migration routing. Such simultaneous changes may result in larger than expected changes in survival than the effect of routing alone on overall survival.

Interpretation of these analyses must also consider that small changes in absolute survival (e.g., the 3-5 percentage point differences shown in Figure 2) could translate to a large effect to a population, especially in years when overall Delta survival is low. The 2-7 percent increase in Delta survival that would occur if entrainment into the interior Delta were eliminated (Perry et al. (2012) resulted in a 10-35% relative change in survival for five of the six release groups in that study.

2.5.1.2.7.2.3   Winter-Run Exposure and Risk

The differences in flow routing characterized by the analysis of Section 2.5.1.2.7.2.1 do not necessarily translate directly into biological outcomes between scenarios; therefore the significance of these differences in the scenarios is uncertain. However, because the Perry et al. 2016 (in review) method of Section 2.5.1.2.7.2.2 uses hydrologic data coupled with acoustic tag tracking of Chinook salmon smolts, that method provides the behavioral component that is lacking from the analysis of the hydrologic model. Because of this better characterization of fish behavior, the analysis from the Perry et al. 2016 model is considered with a higher weight of evidence than the hydrologic model analysis for the junctions at Sutter Slough, Steamboat Slough, Georgiana Slough, and the DCC in the Sacramento River. However, because the flow routing analysis provides flow characterizations for junctions where 1) there is little or no associated acoustic tagging data and 2) for junctions that are not covered in the Perry et al. 2016 model, the flow routing analysis of Section 2.5.1.2.7.2.1 will be used to assess potential migratory outcomes at interior Delta junctions (such as the head of Old River, Turner Cut, Columbia Cut, Middle River, and the mouth of Old River).

As described in the flow routing analysis of Section 2.5.1.2.7.2.1, there will be changes in proportion of flow entering key junctions for the PA. At Steamboat Slough, the proportion of flow into the distributary decreased by more than 5 percent for the PA in February and March of below normal and dry years (Section 2.5.1.2.7.2.1, Table 2-1) and in January and April of above normal years (Table 5.4-12). The reductions in proportional flow into this particular distributary would be an adverse migratory condition; Steamboat Slough provides a route of higher survival for winter-run Chinook salmon smolts by removing exposure to both the Georgiana Slough and DCC junctions, and eliminating the risk of entrainment into the interior Delta. Results also show that 5-12 percent more flow enters Georgiana Slough for the PA during February and March of below normal and dry years (Table 2-1). This is an adverse migratory condition for winter-run Chinook salmon since it indicates an increased proportion of outmigrating fish would enter into the interior Delta and be subject to a route of lower survival than that of the mainstem Sacramento River. The largest proportion of winter-run Chinook salmon smolts are expected to enter the Delta in February during these drier water year types (Figure 1 and 2 in section 2.5.1.2.7.1.2), and typically enter the Delta in November and December (Table 3 in section 2.5.1.2.7.1.2). Additionally, since over 60% of the sampled population is present in the Delta during March, and in dry years the population is mostly present during February-April, any

negative changes in flow or migratory patterns during these particular months and water year types due to the operations of the PA could have a more significant effect on the population than changes in other months or water year types.

In the South Delta, at Turner Cut, proportion of flow entering the distributary is consistently higher for the PA during winter-run Chinook salmon migratory months of February through April; this would be an adverse effect of the PA operations because smolts migrating through corridors in the south Delta have low survival probability and high predation risk. At Columbia Cut, the PA would offer some beneficial effects in the wet water year types of February and March, but an adverse effect of more potential entrainment in April. At the Middle River and the mouth of Old River, the PA offers some benefit to outmigrating smolts in the wetter water year types.

As noted above, the PA increases the potential for winter-run Chinook salmon migrating down the Sacramento River to enter the interior Delta through Georgiana Slough. This can result in adverse effects from the relatively low survival probability and high predation risk in that migration route. Any winter-run Chinook salmon that may be in the San Joaquin River would, based on flow routing, potentially benefit from a HOR gate due to reduced entry into Old River and reduced entrainment at the south Delta export facilities. However, only a small proportion of the winter-run Chinook salmon population would potentially be in the San Joaquin River near the head of Old River. The effects of PA operations on winter-run Chinook salmon that are in the south Delta are better examined using other methods that are applied in this opinion (i.e., Section 2.5.1.2.7.3 South Delta Salvage and Facility Entrainment).

Overall, this analysis indicates that the PA operations would increase the risk of juvenile winter-run Chinook salmon routing to lower survival routes in the central Delta and reduce the probability of entering or remaining in higher survival routes of Steamboat Slough and the Sacramento River. The effects are most prominent in drier water year types during the peak migratory months that are especially important for winter-run Chinook salmon juveniles during drier hydrology. This is an adverse effect of the PA for most rearing and outmigrating winter-run Chinook salmon juveniles.The Perry et al 2016 entrainment model described in section 2.5.1.2.7.2.2., gives a detailed look into changes in migratory patterns for winter-run Chinook salmon. Of the three migratory patterns used in the model, two are specific for winter-run Chinook salmon (i.e.,., early and late run timing). Since migration into the Delta is hydrology driven for winter-run Chinook salmon, monthly distribution varies year to year. Of the three migratory patterns, the late arriving temporal distribution (Section 2.5.1.2.7.2.2; Figure 1) has the least change in routing between scenarios with overall small negative effects of fewer smolts (1-2%) remaining in the Sacramento River for the PA. This is due to reduced routing differences in January-April, the months that matter most for this run timing distribution. The early arriving temporal distribution (i.e., on or before December 31) (Section 2.5.1.2.7.2.2; Figure 1) had larger changes in routing between scenarios ranging from 1-5 percent in key months and water year types. November and December become important migratory months for winter-run Chinook salmon in the early run timing because fall and early winter storms create the upstream pulse flows that trigger their migration (del Rosario et al 2013). The equal distribution timing showed the largest routing changes due to the DCC being open more in October through December and June for the PA and the winter-run Chinook salmon smolt population being evenly distributed into the model from October through June. While the equal distribution run is not an accurate representation of winter-run Chinook salmon outmigration, its application in this analysis allows

assessment of entrainment probability equally under all months; this is useful for assessing effect to the four Delta salmonid species (that is, winter-run, spring-run, and fall/late-fall run Chinook salmon, and steelhead), which have varying run timings.

Overall changes in migratory routing in key migratory months for most species (December – June) are not substantial. However, there is a consistent pattern that holds up for all water year types and most months within those water year types of greater entrainment into the interior Delta (Georgiana Slough and DCC combined) for the PA. This is a negative effect of PA operations which would be one contributing factor to reduced overall through-Delta survival for Sacramento River basin salmon smolts. The PA operations also result in more frequent opening of the DCC gate (especially in October and November), resulting in a greater probability of entrainment into that low survival route.

For winter-run Chinook salmon, October or November operations for the PA provides the greatest risk or probability of interior Delta entrainment during the migration period. Winter-run Chinook salmon juvenile populations (fry- and smolt-sized) are expected to be rare in October and only common in November during wetter water year types (Table 3 section 2.5.1.2.7.1). Therefore, November is an important month for life history diversity of this endangered species. Unless the monitoring system is adequate to detect listed fish in the Delta with a high level of accuracy, the increased risk of DCC entry remains, especially for juveniles that may be advected back upstream and exposed to the DCC junction multiple times. Additionally, the minimum bypass flows in November are not designed to be protective of outmigrating listed species unless a real time monitoring trigger is enacted. In the drier water year types, there is a slight increase (~2% median) in interior Delta entrainment during the month of March, a key migratory month during which at least 60 percent of the winter-run Chinook salmon population is usually present.

The results of the Perry et al. 2016 model indicate that during PA operations, the migratory conditions for winter-run Chinook salmon will be best when the diversions are operating at low level pumping or Level 1 and under a late-arriving temporal distribution. However, this statement does not consider flow-survival relationship differences by month between the scenarios or the effects of a later arriving temporal distribution on the population overall. It only summarizes under what PA diversion levels and distribution timing the PA has the least adverse effect on migrating smolts when compared to the NAA scenario. Likewise, a uniform run timing distribution of winter-run Chinook juveniles under Level 3 operations of the PA, would likely experience the most adverse migratory conditions as compared to NAA.

To better understand how these analyses on hydro-dynamics and entrainment would affect survival between the scenarios, we have used biological models that couple the flow-survival relationships with the entrainment and hydrodynamics studies that were described in multiple sections (BO flow survival section xyz)

2.5.1.2.7.2.4   Spring-Run Exposure and Risk

2.5.1.2.7.2.5   Steelhead Exposure and Risk

2.5.1.2.7.2.6   Green Sturgeon Exposure and Risk

2.5.1.2.7.2.7   Fall/Late Fall-Run Exposure and Risk

2.5.1.2.7.3 South Delta Salvage and Entrainment

The Federal Jones Pumping Plant and the State Banks Pumping Plant draw massive volumes of water off the Old River channel in the South Delta. With water flowing to these water export facilities, fish, including listed species, are entrained to the South Delta and get lost to the facilities. The fish loss is back calculated using the fish salvage data collected at Tracy and Skinner fish collective facilities. In this section, we first present the historical data of juvenile salvage and loss at the water export facilities and then provide estimated juvenile losses under the PA and NAA.

The number of juvenile fish salvaged per day was estimated from the number (counts) of fish sampled. The ratio of the pumping duration to the sampling duration was used to expand the count data to an estimate of the number of fish salvaged in the pumping time period, which was further expanded to the number of fish salvaged per day (24 hours). The annual salvage or loss is the sum of daily salvage or daily loss during a brood year. Salvage or loss data were presented for both adipose clipped and unclipped juveniles. Chinook salmon juvenile salvage and loss data were obtained from ftp://ftp.dfg.ca.gov/salvage/DOSS_Salvage_Tables. Annual hatchery-reared juvenile release data were provided by ICF (Hassrick2016). Annual winter-run juvenile production estimate (JPE) data were provided by NMFS (Oppenheim2016).

In the BA, two methods were used to assess potential differences in juvenile loss between the PA and NAA. The first one is the loss-density method. As described in the BA, for each species in each month at each facility, the loss-density was calculated as the number of fish loss divided by the volume of exported water (thousand acre-foot), assuming a linear relationship between fish loss and water export volume. The loss-density was obtained using historical water export and salvage-derived loss data for water years1995–2009. These loss-density data provided the basic estimates of fish density (number of fish salvaged per volume of water exported) that were subsequently multiplied by simulated water export data for the CALSIM modeling period of 82 years (1922–2003) to assess differences between the PA and NAA.

The second method as described in the BA applied to hatchery-reared winter-run juveniles only. Zeug and Cavallo (2014) developed regression models that linked historical water export and Sacramento River flow to the historical proportional loss of hatchery-reared juvenile winter-run. The established models were then used to estimate winter-run juvenile losses under the PA and NAA using simulated 82-year data for water exports and Sacramento River flows.

Note that these two methods do not account for differences in salvage or loss that could occur because of other operational effects, e.g., changes in juvenile salmonid routing because of the NDD or the HOR gate. In addition, the method does not account for changes in the system under the PA that could result in increased entrainment into the interior Delta due to lowered north Delta flows or for benefits that might be expected for San Joaquin Basin fish emigrating past the HOR gate under the PA that would keep them from entering the Old River.

2.5.1.2.7.3.1   Winter-run Exposure and Risk

2.5.1.2.7.3.1.1   Winter-run Historical Salvage and Loss Data Analysis

The average annual adipose fin clipped winter-run juvenile salvage and loss from brood year1999 to2014 were 1,656 and 4,607 juveniles, respectively (Table **Error! No text of specified style in document.**-9). The average proportional loss, which is the annual total loss divided by the annual number of hatchery-reared and released winter-run juveniles, was2.78% (Table **Error! No text of specified style in document.**-9).

*Table **Error! No text of specified style in document.**-9. Annual adipose fin clipped winter-run juvenile salvage and loss from brood years1999 to2014*

Brood Year	Tot_Salvage_Clip	Tot_Loss_Clip	# Juvenile Released	Loss/Release
1999	987	2,482	153,908	1.61%
2000	965	3,295	30,840	10.68%
2001	2,259	6,734	166,206	4.05%
2002	7,751	22,748	252,684	9.00%
2003	6,094	19,319	233,613	8.27%
2004	1,103	3,964	218,617	1.81%
2005	477	1,251	168,261	0.74%
2006	1,353	2,034	173,344	1.17%
2007	2,919	5,618	196,288	2.86%
2008	179	435	71,883	0.60%
2009	1,230	2,356	146,211	1.61%
2010	463	1,449	198,582	0.73%
2011	460	1,210	123,859	0.98%
2012	187	595	194,264	0.31%
2013	6	12	181,857	0.01%
2014	62	214	193,155	0.11%
Mean	1,656	4,607	168,973	2.78%
Median	976	2,195	177,601	1.39%
SD	2,223	6,714	56,556	3.43%
95% CI	1,089	3,290	27,712	1.68%

The average annual unclipped winter-run sized juvenile salvage and loss from brood years1992 to2015 were1,299 and3,450 juveniles, respectively (Table **Error! No text of specified style in document.**-10). The average proportional loss of unclipped juveniles, which is the annual total

loss divided by the annual JPE, was1.08% (Table **Error! No text of specified style in document.**-10).

*Table **Error! No text of specified style in document.**-10. Unclipped annual winter-run sized juvenile salvage and loss from brood years1992 to 2015*

Brood Year	Tot_Salvage_Unclip	Tot_Loss_Unclip	JPE	Loss/JPE
1992	1,053	4,003	246,157	1.63%
1993	1,337	2,769	90,546	3.06%
1994	1,416	4,582	74,491	6.15%
1995	781	2,376	338,107	0.70%
1996	397	630	165,069	0.38%
1997	726	1,525	138,316	1.10%
1998	1,514	3,715	454,792	0.82%
1999	1,936	5,828	289,724	2.01%
2000	5,932	20,062	370,221	5.42%
2001	1,442	3,331	1,864,802	0.18%
2002	2,277	6,816	2,136,747	0.32%
2003	2,728	7,779	1,896,649	0.41%
2004	469	1,373	881,719	0.16%
2005	1,008	2,601	3,831,286	0.07%
2006	2,764	3,297	3,739,069	0.09%
2007	660	1,292	589,911	0.22%
2008	582	1,515	617,783	0.25%
2009	1,064	1,656	1,179,633	0.14%
2010	1,703	4,360	332,012	1.31%
2011	841	2,079	162,051	1.28%
2012	271	732	532,809	0.14%
2013	192	322	1,196,387	0.03%
2014	53	106	124,521	0.09%
2015	36	56	101,716	0.06%
Mean	1,299	3,450	889,772	1.08%
Median	1,030	2,488	412,507	0.35%
SD	1,253	4,096	1,078,208	1.63%
95% CI	501	1,639	431,365	0.65%

2.5.1.2.7.3.1.2 Winter-run Juvenile Loss Estimates Using the Loss-Density Method

The results of the loss-density method showed that, based on modeled south Delta exports, average loss at the south Delta water export facilities would be lower under the PA than the NAA in all water year types for winter-run Chinook salmon. Juvenile fish loss under the PA would be reduced by 53% for winter-run (Table **Error! No text of specified style in**

document.-11). Note that winter-run loss estimates were normalized by the juvenile production estimate (JPE) entering the Delta.

*Table **Error! No text of specified style in document.**-11. Estimated average number of Juvenile winter-run, spring-run, and steelhead losses at the CVP and SWP water export facilities under the PA and NAA*

Species	SWP			CVP		
	NAA	PA	% Reduction	NAA	PA	% Reduction
Winter-run	5,305	2,717	48.8%	769	327	57.4%

2.5.1.2.7.3.1.3 Winter-run Juvenile Loss Estimates Using the Zeug and Cavallo (2014) Method

Average estimates of proportional losses for all 82 water years were less under the PA than the NAA (Table **Error! No text of specified style in document.**-12). The magnitude of the difference varied between water year types. The proportional losses in wetter years when south Delta water exports were estimated to be lower than in drier years under the PA.

*Table **Error! No text of specified style in document.**-12. Average annual proportional loss of hatchery-reared winter-run juveniles by water year-type from the analysis based on Zeug and Cavallo (2014)*

WYT	Proportional Loss Under NAA	Proportional Loss Under PA	Loss Reduction	% Loss Reduction
W	0.0091	0.0009	0.0082	90.1%
AN	0.0037	0.0010	0.0027	73.0%
BN	0.0033	0.0017	0.0016	48.5%
D	0.0024	0.0016	0.0008	33.3%
C	0.0016	0.0011	0.0005	31.3%
Ave	0.0040	0.0013	0.0028	55.2%

2.5.1.2.7.3.2 Spring-run Exposure and Risk

2.5.1.2.7.3.2.1 Spring-run Historical Salvage and Loss Data Analysis

The average annual adipose fin clipped spring-run juvenile salvage and loss from brood year1999 to2014 were628 and 1,414 juveniles (Table **Error! No text of specified style in document.**-13), respectively. The average proportional loss, which is the annual total loss divided by the annual number of hatchery-reared and released spring-run juveniles, was 0.75% (Table **Error! No text of specified style in document.**-13).

Table ***Error! No text of specified style in document.***-13. *Adipose fin clipped annual spring-run juvenile salvage and loss from brood year1999 to 2014*

Brood year	Tot_Salvage_Clip	Tot_Loss_Clip	# Juvenile Released	Loss/Release
1999	2,226	8,657	171,340	5.05%
2000	270	726	No Data	No Data
2001	2,754	4,373	254,591	1.72%
2002	864	2,520	128,200	1.97%
2003	205	586	No Data	No Data
2004	2,488	3,633	561,920	0.6465%
2005	601	632	No Data	No Data
2006	31	44	5,219,080	0.0009%
2007	107	251	214,159	0.1173%
2008	15	11	108,085	0.0106%
2009	42	73	51,762	0.1414%
2010	276	793	3,258,949	0.0243%
2011	142	289	2,314,266	0.0125%
2012	7	15	92,396	0.0163%
2013	12	8	2,997,011	0.0003%
2014	8	7	2,090,391	0.0003%
Mean	628	1,414	1,343,242	0.75%
Median	174	438	254,591	0.02%
SD	958	2,362	1,673,480	1.46%
95% CI	469	1,157	909,697	0.79%

The average annual unclipped spring-run sized juvenile salvage and loss from brood year1992 to2015 were13,725 and 24,664 juveniles (Table **Error! No text of specified style in document.**-14), respectively.

*Table **Error! No text of specified style in document.**-14 Annual unclipped spring-run sized juvenile salvage and loss from brood year1992 to 2015*

Brood year	Tot_Salvage_Unclip	Tot_Loss_Unclip
1992	7,721	13,265
1993	3,555	3,785
1994	24,200	29,905
1995	26,785	36,851
1996	42,908	54,855
1997	30,597	24,943
1998	46,655	105,615
1999	42,513	90,118
2000	17,940	40,696
2001	8,177	10,206
2002	15,706	40,383
2003	4,534	10,985
2004	14,694	27,319
2005	5,822	13,002
2006	3,378	5,213
2007	5,100	11,771
2008	4,730	8,840
2009	4,068	6,082
2010	17,654	52,505
2011	1,063	2,394
2012	909	2,496
2013	484	349
2014	50	70
2015	158	298
Mean	13,725	24,664
Median	6,772	12,386
SD	14,613	28,151
95% CI	5,846	11,262

2.5.1.2.7.3.2.2   Spring-run Juvenile Loss Estimates Using the Loss-Density Method

The results of the loss-density method showed that, based on modeled south Delta exports, average loss at the south Delta water export facilities would be lower under the PA than the NAA in all water year types for spring-run. Juvenile fish loss under the PA would be reduced by69% for spring-run (Table **Error! No text of specified style in document.**-15).

*Table **Error! No text of specified style in document.**-15. Estimated average number of Juvenile spring-run losses at the CVP and SWP water export facilities under the PA and NAA*

Species	SWP			CVP		
	NAA	PA	% Reduction	NAA	PA	% Reduction
Spring-run	13,161	4,772	63.7%	4,778	1,247	73.9%

2.5.1.2.7.3.3   Steelhead Exposure and Risk [work in progress, results received from DWR too late to incorporate in this version]

2.5.1.2.7.3.3.1   Steelhead Historical Salvage and Loss Data Analysis

The average annual clipped steelhead juvenile salvage and loss from brood year1999 to2014 were xxxx and xxxx juveniles, respectively (Table **Error! No text of specified style in document.**-16). The average proportional loss, which is the annual total loss divided by the annual number of hatchery-reared and released steelhead juveniles, was xxx% (Table **Error! No text of specified style in document.**-16).

*Table **Error! No text of specified style in document.**-16. Annual clipped steelhead juvenile salvage and loss from brood year1999 to2013*

Brood year	Tot_Salvage_Clip	Tot_Loss_Clip	# Juvenile Released	Loss/Release
1999				
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				

Brood year	Tot_Salvage_Clip	Tot_Loss_Clip	# Juvenile Released	Loss/Release
2011				
2012				
2013				

The average annual unclipped steelhead juvenile salvage and loss from brood year1992 to2015 were xxx and xxxx juveniles, respectively. The average proportional loss of unclipped juveniles, which is the annual total loss divided by the annual JPE, was xxx%.

*Table **Error! No text of specified style in document.**-17. Annual unclipped steelhead juvenile salvage and loss from brood year1992 to2015*

Brood year	Tot_Salvage_Unclip	Tot_Loss_Unclip
1992		
1993		
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		
2009		
2010		

Brood year	Tot_Salvage_Unclip	Tot_Loss_Unclip
2011		
2012		
2013		
2014		
2015		

2.5.1.2.7.3.3.2 Steelhead Juvenile Loss Estimates Using the Loss-Density Method

The results of the loss-density method showed that, based on modeled south Delta exports, average loss at the south Delta water export facilities would be lower under the PA than the NAA in all water year types for steelhead. Juvenile fish loss under the PA would be reduced by 41% for steelhead (Table **Error! No text of specified style in document.**-18).

*Table **Error! No text of specified style in document.**-18. Estimated average number of Juvenile steelhead losses at the CVP and SWP water export facilities under the PA and NAA*

Species	SWP			CVP		
	NAA	PA	% Reduction	NAA	PA	% Reduction
Steelhead	7,613	4,995	34.4%	1,536	809	47.3%

2.5.1.2.7.3.4 Green Sturgeon Exposure and Risk [work in progress, data received from DWR too late to incorporate]

2.5.1.2.7.3.5 Fall/Late Fall-Run Exposure and Risk [work in progress, data received from DWR too late to incorporate]

2.5.1.2.7.4 Delta Survival

Several studies conducted on salmonid migration through the Sacramento-San Joaquin Delta provide solid understanding on how Delta inflow affects the variability of juvenile salmonid survival (Perry et al 2010, Perry et al 2013, Newman et al 2003). These studies helped to define the relationship of Sacramento River (Freeport) flow and juvenile salmon survival through the Delta and the importance routing has on migratory success. The acoustic tag studies in particular (Perry et al 2010, Perry and other 2017 in prep) indicated that survival probability increases with increasing flows and changes in survival are steepest when flows are below 30,000 cfs at Freeport. The slope of the relationship decreases at higher flows and the flow survival relationship is strongest in the reaches that transition from riverine to strong tidal influence. This is in line with the assumptions and results in the velocity and entrainment analysis that indicated low, slack and reverse velocities increase entrainment risk and increase travel time. The studies also identify the probabilities of which migratory route in the north Delta is used as a function of flow (Perry et al 2016 in prep, Perry et al 2015). Entrainment into the interior Delta via

Georgiana Slough or Delta Cross Channel (DCC) are increased when flows in the mainstem Sacramento are low, reversing, or stagnant and remaining in the Sacramento or entering Sutter or Steamboat Slough are increased under high inflows (Bureau, Perry et al 2010, Perry and other 2017 in prep). While the mechanisms causing the reduced survival probabilities are likely combinations of reduced velocities, increase in reverse flows, route selection, and increased entrainment into the interior Delta, the flow-survival relationship can be used to collectively evaluate effects of flow changes on through-Delta survival. This biological opinion analyzes the effects of the PA on travel time (section xx), route selection (section xx), entrainment probabilities into Interior Delta (section sxx), and will now discuss the relationships between flows and juvenile salmon survival probabilities.

Two models are used to assess differences in route specific and overall through Delta survival, The Delta Passage Model that was presented in the CWF BA and the Perry 2017 model which is presented in this Biological Opinion. The Perry 2017 model supersedes the analysis that was based by Perry (2010)(CWF BA Section 5.4.1.3.1.2.1.3.3).

2.5.1.2.7.4.1   Delta Passage Model

The BA includes analysis of through-Delta survival using the Delta Passage Model (DPM) (BA Section 5.4.1.3.1.2.1.3.1 *Delta Passage Model: Winter-Run and Sacramento River Basin Spring-Run Chinook Salmon*). The DPM integrates operational effects of the NAA and PA that could influence survival of migrating juvenile winter-run Chinook salmon through the Delta; this includes differences in channel flows (flow-survival relationships), differences in routing based on flow proportions (e.g., entry into the interior Delta, where survival is lower), and differences in south Delta exports (export-survival relationships). The DPM provides estimates of the mean annual probability of survival from Freeport to Chipps Island through four (collective) migratory routes over the five water year types (mainstem Sacramento River, Yolo Bypass, Sutter and Steamboat sloughs, and interior Delta). It also provides total through-Delta survival over the five water year types and the proportion of population migrating through each migratory route under both scenarios.

2.5.1.2.7.4.1.1   Winter-run Exposure and Risk

Results for estimated total through-Delta survival for winter-run Chinook are shown in Figure 2-11. This table also includes mean survival probability by migratory route and water year types. For the NAA, the probability of survival in the Yolo Bypass, Sutter and Steamboat Sloughs, and mainstem Sacramento River migratory routes are relatively higher than the probability of survival in the Interior Delta, which is at most 18% (Figure 2-11).

Winter-run smolt survival through the Delta (i.e., total survival) is generally low. For the NAA, mean total survival ranges from a low of 25% in critical years to a high of 43% survival in wet years. For the PA, smolt survival is reduced in all migratory routes, with the exception of the Interior Delta (Table that is Figure 2-11, Figure 2-12 (boxplot)). For example, survival in the mainstem Sacramento River is reduced across all water year types for the PA, as shown in the 8% relative reduction in survival for below normal and dry years. This pattern of reduced survival, regardless of water year type, is also expected for total survival through the Delta, and for smolts migrating through Sutter and Steamboat Sloughs (Table that is Figure 2-11). The probability of survival for smolts migrating through the Yolo Bypass is not expected to change (Table that is Figure 2-11). The only region where survival is improved for the PA is the Interior

Delta, with the exception in critical water years (Table that is Figure 2-11). The lowest probability of survival is the Interior Delta, where smolts have a 13%-18% probability of survival under current conditions. The probability of entry into the interior Delta is slightly higher for the PA and there is also a slight decrease in the probability of entry into the Sutter and Steamboat routes for the PA. Because of the different survival probabilities for the different routes, the routing results can affect total through-Delta survival when assessing the overall effect of operations

*Table **Error! No text of specified style in document.**-19. Delta Passage Model: Winter-Run Chinook Salmon Mean Through-Delta (Total) Survival, Mainstem Sacramento River survival, and Proportion Using and Surviving Other Migration Routes. Values in parenthesis represent percent change in mean survival under the PA. (Table 5.4 13)*

| WY | Total Survival | | | Mainstem Sacramento River Survival | | | Yolo Bypass | | | | | |
| | | | | | | | Proportion Using Route | | | Survival | | |
	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
W	0.43	0.43	-0.01 (-2%)	0.48	0.46	-0.02 (-5%)	0.22	0.22	0.00 (1%)	0.47	0.47	0.00 (0%)
AN	0.40	0.39	-0.01 (-2%)	0.44	0.42	-0.02 (-6%)	0.16	0.17	0.00 (1%)	0.47	0.47	0.00 (0%)
BN	0.31	0.29	-0.02 (-6%)	0.34	0.31	-0.03 (-8%)	0.06	0.06	0.00 (2%)	0.47	0.47	0.00 (0%)
D	0.30	0.28	-0.02 (-7%)	0.33	0.30	-0.03 (-8%)	0.06	0.06	0.00 (2%)	0.47	0.47	0.00 (0%)
C	0.25	0.24	-0.01 (-4%)	0.27	0.26	-0.01 (-4%)	0.03	0.03	0.00 (0%)	0.47	0.47	0.00 (0%)

| WY | Sutter/Steamboat Sloughs | | | | | | Interior Delta (Via Georgiana Slough/DCC) | | | | | |
| | Proportion Using Route | | | Survival | | | Proportion Using Route | | | Survival | | |
	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
W	0.29	0.28	-0.01 (-2%)	0.52	0.50	-0.02 (-4%)	0.26	0.26	0.00 (2%)	0.18	0.23	0.05 (28%)
AN	0.30	0.29	-0.01 (-2%)	0.49	0.46	-0.02 (-5%)	0.26	0.27	0.01 (2%)	0.17	0.20	0.03 (19%)
BN	0.31	0.30	-0.01 (-2%)	0.38	0.35	-0.03 (-7%)	0.27	0.28	0.01 (2%)	0.14	0.15	0.01 (5%)
D	0.30	0.30	-0.01 (-2%)	0.37	0.34	-0.03 (-8%)	0.27	0.28	0.01 (2%)	0.14	0.14	0.00 (0%)

C	0.29	0.29	0.00 (-1%)	0.31	0.30	-0.01 (-4%)	0.29	0.29	0.00 (1%)	0.13	0.12	0.00 (-1%)

Note: Survival in Sutter/Steamboat Sloughs and Interior Delta routes includes survival in the Sacramento River prior to entering the channel junctions.

The results of the DPM show a logical manifestation of application of a flow-survival relationship – that survival for the PA, which has lower flows due to the operations of the NDD, has lower survival probabilities. The DPM results show an increase in survival in the interior Delta due to reduced south Delta exports which is expected to influence survival in the interior Delta. However, the increase in survival for the interior Delta does not necessarily mitigate for the reduction in survival in the primary north Delta migratory routes (Table 5.4-13). Based on the steeper flow-survival relationship that would occur when Sacramento River flows are under 30,000 cfs. The difference in survival probability between the scenarios is likely to be more pronounced in drier years than for wetter years with a similar level of decrease. In other words, the PA operations would likely reduce through-Delta survival more during drier years than wetter years (Figure 2-13, BA Figure 5.4-8).
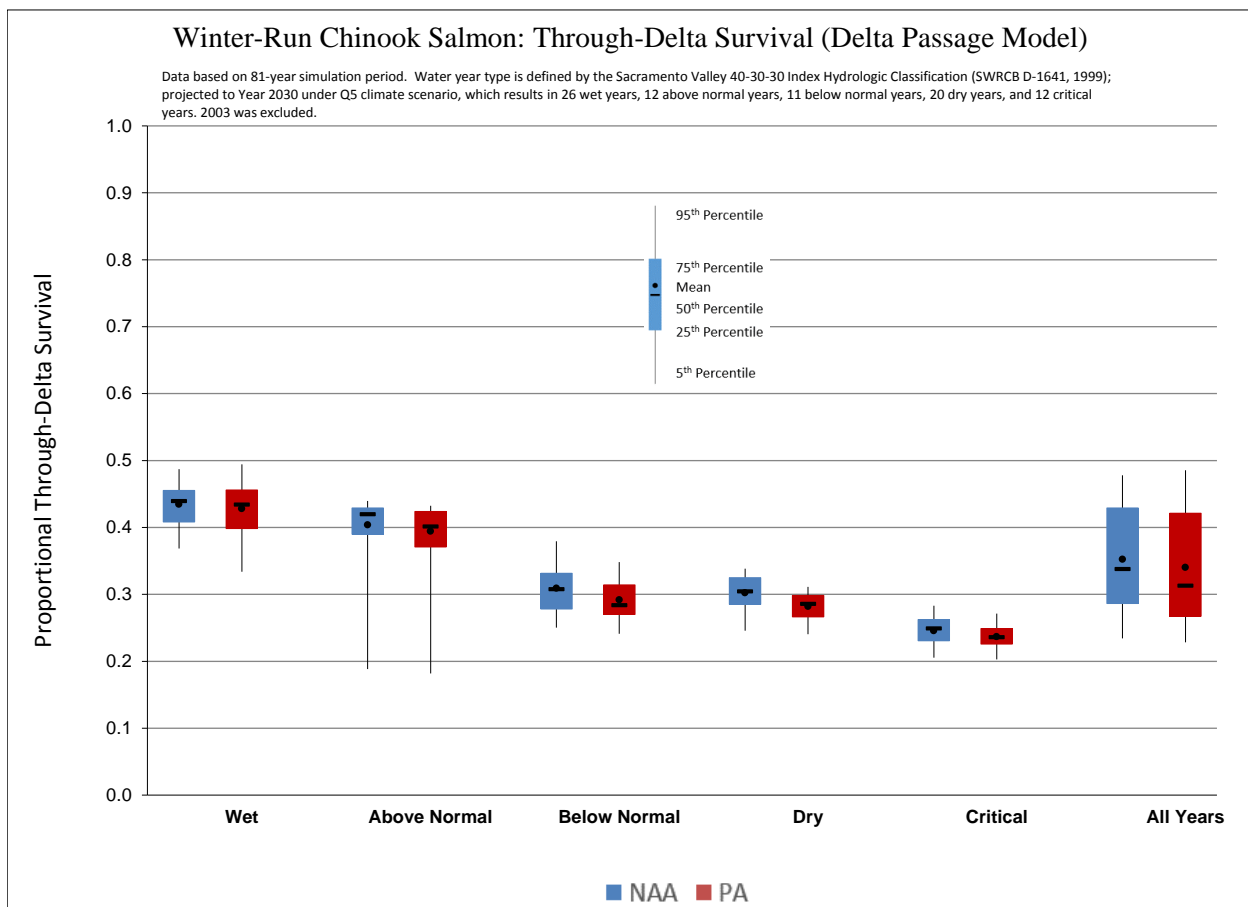
*Figure **Error! No text of specified style in document.**-13. Figure 5.4 8. Box Plots of Winter-Run Chinook Salmon Annual Through-Delta Survival Estimated from the Delta Passage Model, Grouped by Water Year Types*

Because winter-run Chinook only spawn in the upper Sacramento River, exposure to the NDD intakes and operations of the PA will affect all of the population with the exception of the

proportion that may enter the Yolo Bypass. This model estimated a range from 3% in critical years to 22% in wet years would enter the Yolo Bypass (Table 5.4-13). This estimation includes an assumption that there would be more access to Yolo in drier year types due to a notched weir that is currently in the planning stages.

Overall, the absolute mean reduction in survival is 1% to 2% for the PA, resulting in a relative survival reduction of 2-7% depending on water year type (Table 5.4-13). This is a notable survival reduction for an endangered species, especially if it occurs on a frequent (e.g., annual) basis. Considering this, the DPM results indicate an adverse effect for outmigrating winter-run Chinook salmon smolts during all water year types. This is due to an increase in routing to lower survival routes and a reduction in flow that impacts survival particularly in below normal and dry water year types. Survival during the drier water year types are about 25% lower on average than the above normal and wet water year types. Therefore, even a small change in survival impacts the population more resulting in 8% relative change in survival during those years.

2.5.1.2.7.4.2 Perry 2017 Flow-Survival Model

The Perry 2017 flow survival model combines equations from statistical models that estimate the relationship of Sacramento River inflows (measured at Freeport) on reach-specific travel time, survival, and routing of acoustic-tagged juvenile late-fall Chinook salmon. Given these equations, daily cohorts of juvenile Chinook salmon migrating through the Delta under the CalSim simulations of the Proposed Action (PA) and No Action Alternative (NAA) were simulated. Daily Delta Cross Channel gate operations from the DSM2 simulations of PA and NAA were also included. Statistical analysis of travel time and survival in eight discrete reaches of the Delta was used for the assessing travel time and survival under the PA and NAA scenarios. The data for the analysis consisted of 2,170 acoustic-tagged late-fall Chinook salmon released during a five-year period (2007-2011) over a wide range of Sacramento River inflows $(6,800 – 77,000 \text{ ft}^3/\text{s}$ at Freeport). This analysis was based on acoustic telemetry data from several published studies where details of each study can be found (Perry et al. 2010, 2013; Michel et al. 2015).

The simulation output for each day was summarized to provide a number of useful statistics for each daily cohort:

- The proportion of fish using each unique migration route.

- The mean survival for each unique migration route.

- Overall survival through the Delta, calculated as the mean survival over all individuals.

- Median travel time by route and over all routes.

- Daily difference in survival and median travel time between PA and NAA scenarios.

The difference in daily through-Delta survival between PA and NAA was summarized with boxplots that display the distribution of survival differences among years for a given date or for given months. To understand how these differences arise, it is useful to examine how the individual components of migration routing, survival, and travel time contribute to overall survival in a particular year. In this section we focus on differences in overall through-Delta survival and survival differences by migratory route. Figures 1x and 2x, illustrate detailed model output for 1943, a wet water year that exhibited bypass flows (flow remaining in the Sacramento

River below the North Delta Diversion) ranging from <5,000 ft^3/s to > 50,000 ft^3/s. Differences in migratory route taken and travel time between the scenarios are presented in section (Travel time sect and Migratory route section – to be done prior to draft)
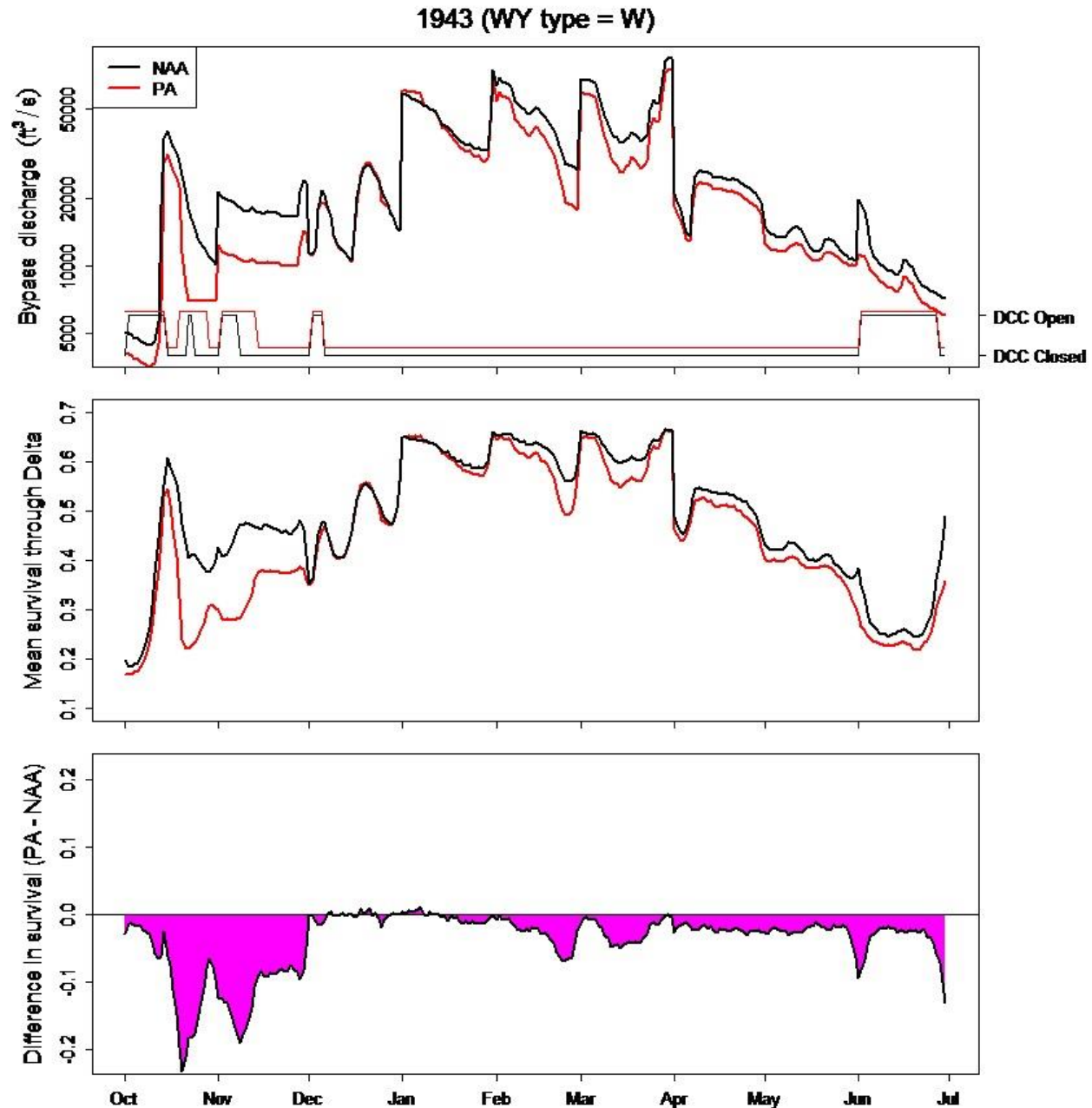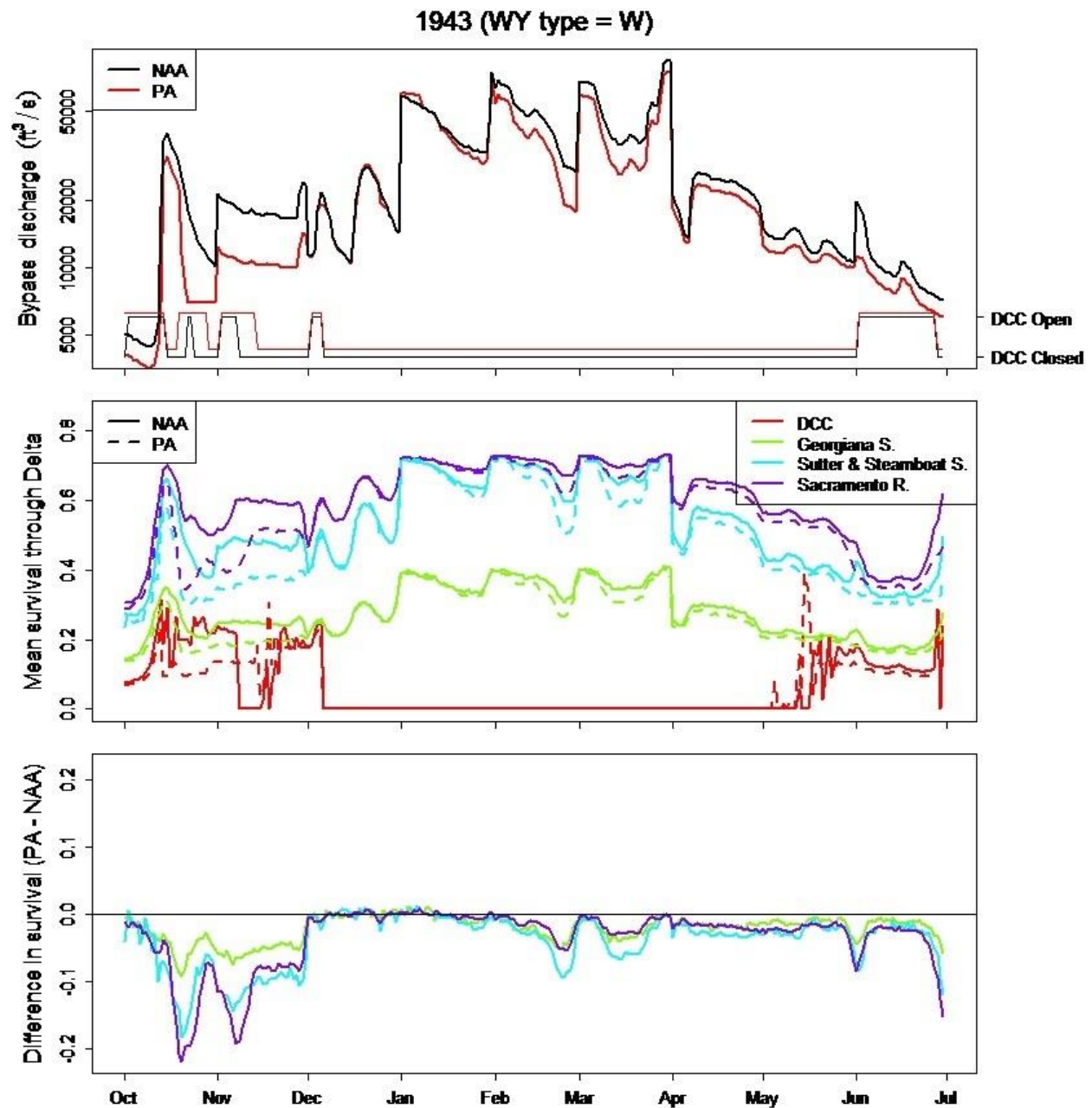

*Figure **Error! No text of specified style in document.**-14. Mean daily survival through the Delta simulated for the Proposed Action (PA) and No Action Alternative (NAA, middle panel)*

Heavy lines in the top panel shows bypass discharge and thin lines show DCC operation of open or closed on the second y-axis. The bottom panel shows the difference in daily survival between

scenarios. Discharge in the top panel is shown on a logarithmic scale to highlight variation in discharge when discharge is low.

*Figure **Error! No text of specified style in document.**-15. Mean daily route-specific survival through the Delta simulated for the Proposed Action (PA) and No Action Alternative (NAA, middle panel).*

Heavy lines in the top panel shows bypass discharge and thin lines show DCC operation of open or closed on the second y-axis. The bottom panel shows the difference in daily route-specific

survival between scenarios. Differences in Delta Cross Channel survival is not shown owing to difference in daily operations of the DCC between scenarios.

As was discussed above in sections (travel time and migration routing sections of BO). Delta inflow, specifically Freeport flow, is used as a predictor of survival, travel time and route entrainment into Sutter and Steamboat Sloughs, Georgiana Slough and DCC gate when open. We discussed in section (travel time section) how the different Levels in the Bypass rules (Levels 1,2 and 3) during the months of December through June affect velocities below the intakes. Level 1 operations offered the most protection of the three levels due to higher Freeport inflows before diversions can occur. Here we examine through-Delta survival under the PA using the Calsim modeling of the scenario which contained diversions at all three levels (PA) and additionally with a scenario that restricts diversions to no greater then Level 1 during December to June (L1).

Under real time operations, the NDD would be operated within the range of Levels 1-3, depending on risk to fish and adherence to screening and reverse flow velocity criteria as well as consideration for other factors such as water supply and other Delta conditions. Additionally, real time operations will implement pulse protection periods when primary juvenile winter-run Chinook salmon migration is occurring. Post-pulse bypass flow operations will remain at Level 1 pumping while juvenile salmonids are migrating through and rearing in the north Delta, unless it is determined through initial operating studies that an equivalent level of protection can still be provided at Level 2 or 3. The specific criteria for transitioning between and among pulse protection, Level 1, Level 2, and/or Level 3 operations will be based on real-time fish monitoring and hydrologic/behavioral cues upstream of and in the Delta that will be studied as part of the PA's Collaborative Science and Adaptive Management Plan (BA Section 3.4.6). Analyses in the BA characterize PA operations with the full range of pumping; that is, operations allow the NDD to operate at Level 3 if all required flow criteria are met. The Perry 2017 analysis was applied to an additional operational scenario that provides a lower bookend of pumping. This scenario limits diversions at the NDD to amounts prescribed by Level 1 (hereto knowing as "Level 1 Only" or L1O). NMFS has evaluated this scenario to provide context for the range of effects that may be experienced by migrating salmonids given that the PA states that post-pulse bypass flow operations will remain at Level 1 pumping while juvenile salmonids are migrating through and rearing in the north Delta. All other operational components remained unchanged.

Below are figures depicting how survival changes under Oct-Nov Bypass rules and how survival differs between pumping Levels 1, 2, and 3 under December to April operations(Figures 2.1 and 2.2). As diversions transition from Level 1 to Level 3, the peak difference in survival rises and shifts to the left on the X axis as a result of being able to divert more at lower flows under each successive operating level (Figure 2-23). Figures 2.1 and 2.2 were produced under the assumption of constant Freeport flows during a cohort's migration through the Delta, whereas the simulations performed using the CalSim results account for daily variation in Freeport flows.
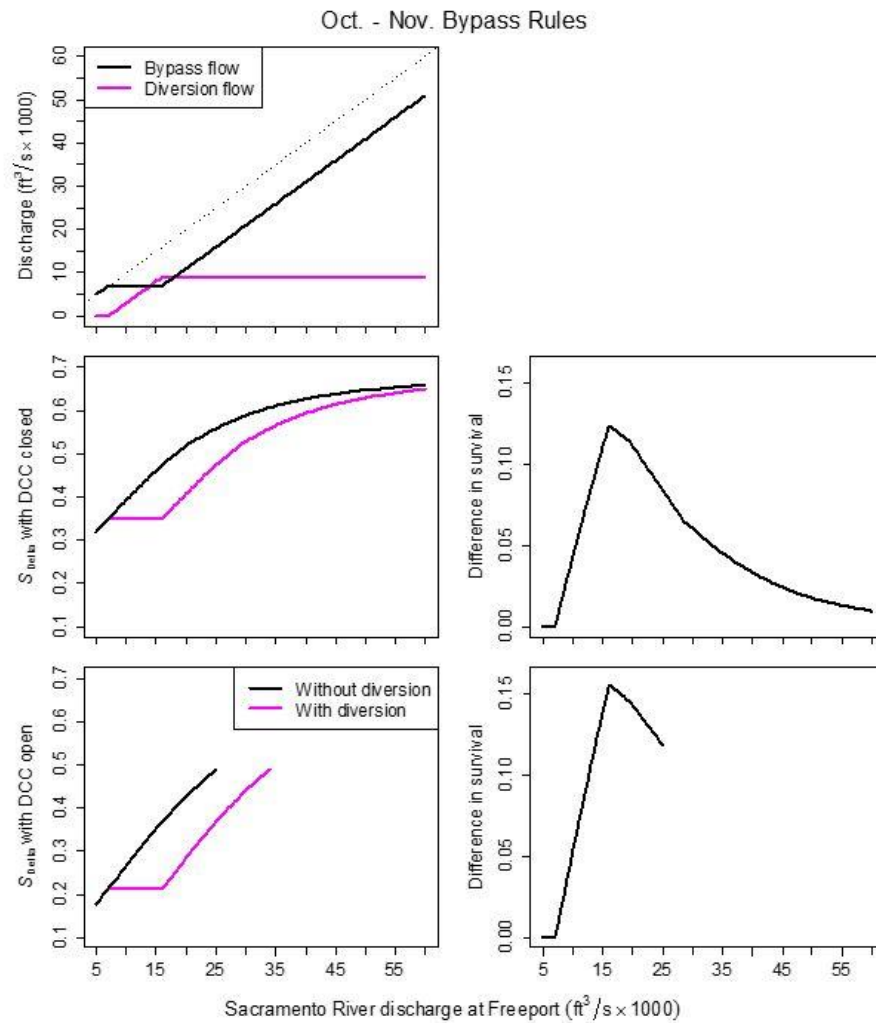
*Figure **Error! No text of specified style in document.**-16. Effect of North Delta Diversion (NDD) on bypass discharge (top row), Delta survival probability with Delta Cross Channel (DCC) closed (middle row), and Delta survival with the DCC open for Oct. – Nov Bypass rules*

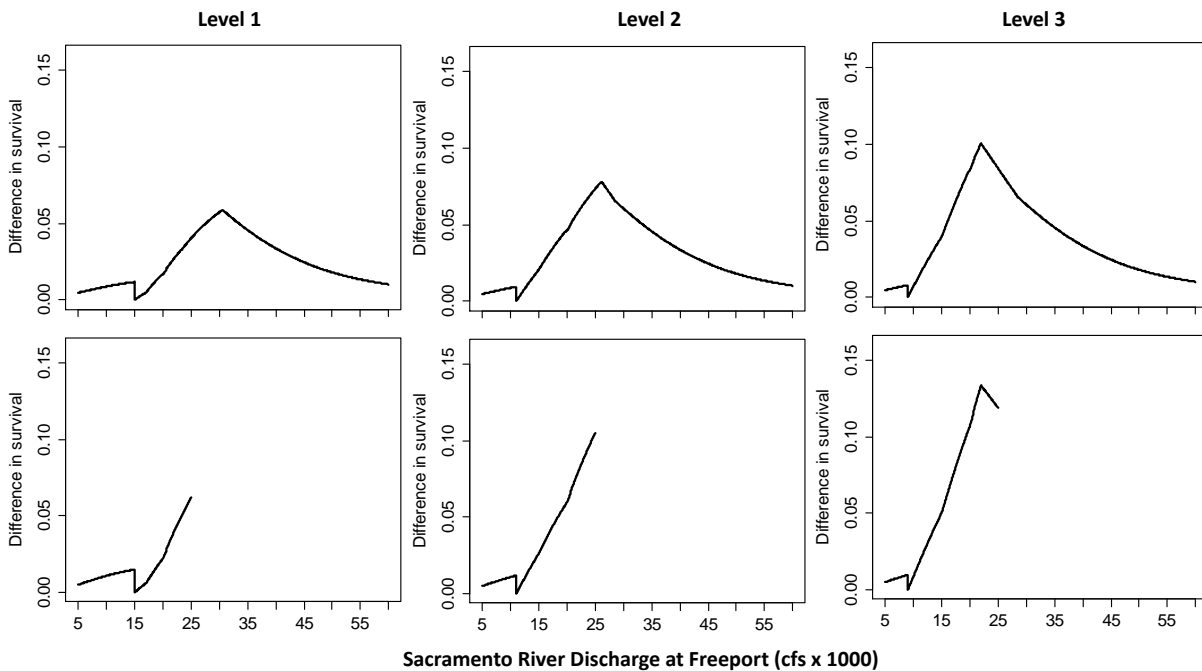In the top panel, the dotted line shows bypass discharge when diversion discharge is zero.

*Figure **Error! No text of specified style in document.**-17. December-April effect of North Delta Diversion (NDD) on Delta survival probability with Delta Cross Channel (DCC) closed (top row) and Delta survival (bottom row) with the DCC open for Level 1-3 post-pulse operations for Dec. - Apr.*

The Perry 2017 model shows a pattern of reduced daily survival probabilities for smolts migrating through the Delta for each month of the salmonid migration period and across each water year type for PA operations (FIGURE 1 –top panel). Furthermore, the boxplots in Figure 1 show that during at least 75 percent of the years (e.g., 75th percentile) survival is estimated to be reduced for PA operations for each month, from October through June, with the exception of April. Under the more protective L1 scenario, the survival probabilities remain reduced each month of the migration period with at least 75% of years estimated to have survival reductions, with the exception of April (Figure 1 middle panel). During April of both PA and L1 operations, survival is estimated to be the same or reduced for 75% of the years (Figure 1).
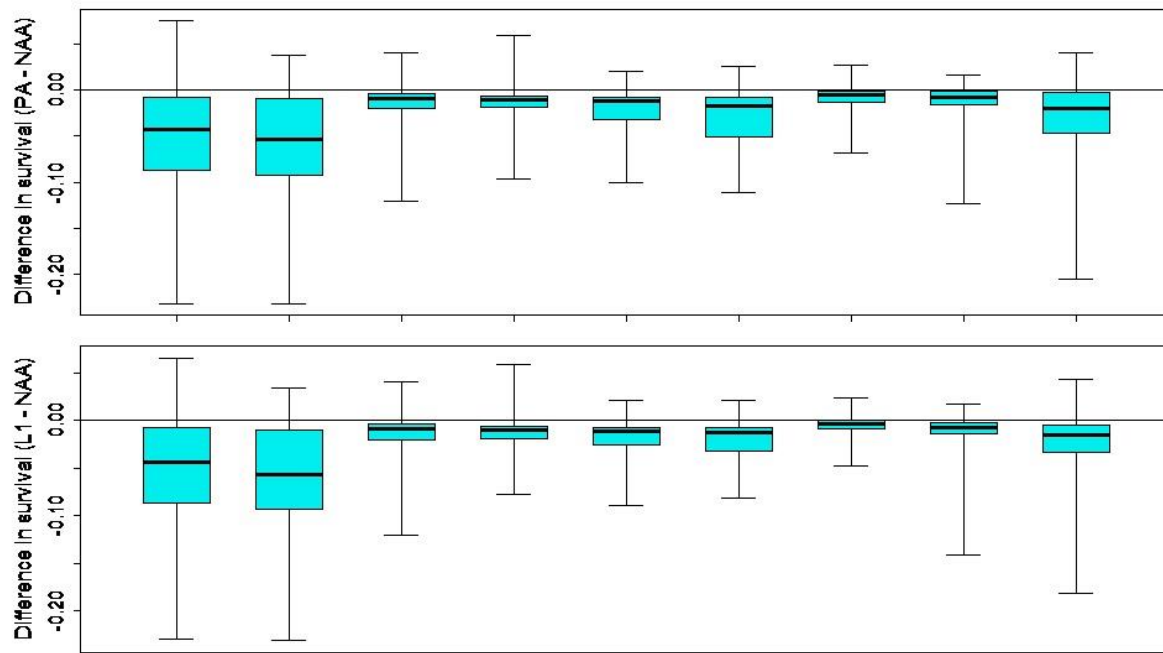
*Figure **Error! No text of specified style in document.**-18. Boxplots of differences in through-Delta survival between the NAA, PA, and Level 1*

Each box plot represents the distribution of daily survival differences among years for a given month. The point in each box represents the median, the box hinges represent the 25th and 75th percentile, and the whiskers display the minimum and maximum.

Survival is reduced under operations of the PA/L1O because reduced Sacramento River flow at Freeport results in higher mortality rates for outmigrating smolts (Perry et al multiple years, Newman 2003). Differences by month and water year type are summarized noting potential species presence and likely operational changes that could occur when following transition criteria to move from Level 1 to Level 3 throughout the migration season.

Differences in Survival by Month

The reduction in survival under the PA is greatest in October and November when few juvenile salmon are expected to be in the Delta (Table 2-20). The primary reason survival is predicted to be greatly reduced in these two months is due to the fact that Bypass rules are not protective unless winter-run Chinook are detected and real time management criteria are triggered. If winter-run Chinook are detected a pulse protection flow and/or May Level 1 operations criteria will be enacted. Therefore survival reductions for winter-run would more likely fall within a range of the top 75% resulting in an 8.7% reduction to a 7.6% increase in October and a 9.2% reduction to a 3.8% increase in survival. Late-fall run and undetected winter run would experience the full range of survival reductions shown here if a trigger is not enacted.

*Table **Error! No text of specified style in document.**-20. Absolute percent change in survival over all water year types.*

Reduction in survival under PA by month all wyt	Median reduction in survival	Reduction in survival for middle 50% of years (interquartile)	Reduction in survival for 25% of years (minimum to first quartlile)	Reduction (or increase) in survival for 25% of years (third quartile to maximum)
October	4.3	8.7 to 0.7	23.3 to 8.7	0.7 to (+7.6)
November	5.4	9.2 to 0.9	23.3 to 9.2	0.9 to (+3.8)

Survival is generally lower in these two months compared to December through May due to seasonally lower inflow at Freeport, negative velocities are more common and adverse routing is more likely to occur especially if the DCC gate is open. The biological effect of lowered and negative velocities is manifested in increased travel time for migrating smolts. October and November have the largest median change when comparing PA/L1 to NAA resulting in approximately 1.2 to 1.3 days longer travel time respectively (ref, stat table or appendix).

Additionally, when the DCC gate is open and velocities are low or negative near the Georgiana Slough junction, the probability of entrainment into the interior Delta is increased. This would tend to happen more during October and November (and sometimes in December and June) because the DCC gate may be open during these months and there is no criteria to avoid reverse flows caused by diversions during October and November unless a flow trigger is initiated.

The changes in travel time documented by this model were presented in section xyz (travel time section) and the changes in routing between the scenarios were presented in section xyz (migration routing section)

The months of December through April, the month of May and the month of June all have Bypass flow criteria as specified in Table 3.x.x in appendix xyz. The values associated with the boxplots in Figure 1 are described below (Table 2). Following the table is a brief synopsis of species presence by month and operational changes during these months.

*Table **Error! No text of specified style in document.**-21. Absolute percent change in survival over all water year types.*

Monthly survival reduction under PA or L1 compared to NAA	Median reduction in survival	Reduction in survival for middle 50% of years (interquartile)	Reduction in survival for 25% of years (minimum to first quartlile)	Reduction (or increase) in survival for 25% of years (third quartile to maximum)
December (PA)	0.9	1.9 to 0.3	12 to 1.9	0.3 to (+4.0)
December (L1)	0.9	2.1 to 0.4	12 to 2.1	0.4 to (+4.1)
January (PA)	1.0	1.9 to 0.6	9.6 to 1.9	0.6 to (+6.0)
January (L1)	1.0	1.9 to 0.6	7.7 to 1.9	0.6 to (+5.9)
February (PA)	1.2	3.2 to 0.7	10.1 to 3.2	0.7 to (+2.1)
February (L1)	1.1	2.5 to 0.7	8.9 to 2.5	0.7 to (+2.1)
March (PA)	1.6	5.0 to 0.8	11.2 to 5.0	0.8 to (+2.6)
March (L1)	1.3	3.2 to 0.7	8.2 to 3.2	0.7 to (+2.1)

Monthly survival reduction under PA or L1 compared to NAA	Median reduction in survival	Reduction in survival for middle 50% of years (interquartile)	Reduction in survival for 25% of years (minimum to first quartlile)	Reduction (or increase) in survival for 25% of years (third quartile to maximum)
April (PA)	0.5	1.2 to 0.0	6.8 to 1.2	0.0 to (+2.7)
April (L1)	0.4	0.0 to 0.0	4.8 to 0.9	0.0 to (+2.4)
May (PA)	0.8	1.6 to 0.1	12.4 to 1.6	0.1 to (+1.7)
May (L1)	0.8	1.4 to 0.2	14.1 to 1.4	0.2 to (+1.7)
June (PA)	2.0	4.6 to 0.3	20.5 to 4.6	0.3 to (+4)
June (L1)	1.5	3.3 to 0.5	18.1 to 3.3	0.5 to (+4.3)

December is the first month when the ND diversions are operating under the Level 1,2,3 criteria of the PA. In December, the differences in survival between PA and NAA are more modest with median survival reduction under the PA of just under 1%. December will have more juvenile salmonid presence than October and usually more than November with the possibility of several runs being present in the Delta. Level 2 or Level 3 operations are rarely enacted during this month so the results between PA and L1 are very similar.

In January, median reduction in survival under PA is at 1% with a range from a 9.6% reduction to a 6% increase in survival. Several species at different life-stages start to become common in the Delta during January. Level 1 operations is the common operating criteria during this month therefore there is little change between PA and L1 survival reductions as compared to NAA.

February median reduction in survival under the PA was 1.2% and ranged from a 10% reduction to a 2% increase in survival. It is possible for all four chinook species as well as steelhead to be present in the Delta during February. February is the month when transition to Level 2 and 3 pumping can really start to occur especially in the wetter years when the criteria to move to the next level can start to be met. L1 shows modest improvements over PA likely due to Level 1 being the most common operation in drier years and/or flows are seasonally high enough in February that survival differences between the levels are no longer applicable. When Freeport flows are at~ 30,000 cfs, all levels are diverting the maximum amount of 9,000 cfs.

March is a key migratory month for many species and a peak month for winter-run Chinook presence. It contains some of the larger survival reductions under the PA. In March, median reduction in survival under PA is at 1.6% with a range from 11.2% reduction to a 2.6% increase in survival. It is very likely that all salmonids will be rearing or migrating in the Delta during March. The main improvements L1 has over PA is for the 25% of the years with the biggest increase in survival reductions under the PA.

April is another key migratory month where all chinook species may be found and it is a peak month for spring-run Chinook in the Delta. Median reduction in survival during April is 0.5% with a range from 6.8% reduction to a 2.7% increase in survival under the PA. April and May are protected by a spring outflow criteria specifically designated for longfin smelt. Although, Level 2 and 3 could be enacted if bypass flow criteria has been met, the spring outflow seems to control diversions to the extent that April inflows below the diversion are more similar to NAA then any other month. L1 offers modest improvement over PA operations particularly in the 25% of years that have the largest survival reduction.

In May it is possible but less common to see all chinook species in the Delta but it is an important migratory month for at least two of the Chinook species. Median reduction in survival under PA is at 0.8% with a range from 12.4% reduction to a 1.7% increase in survival. May is operated under a separate set of Bypass rules which allows more diversions under lower flows then possible during December through April rules. This may be one reason why survival reductions are increased when compared to April even though May also benefits from the spring outflow criteria designated for longfin smelt. L1 offers modest improvements over PA operations during this month.

June is the last month under the NDD Bypass levels rule. June is operated under a separate set of Bypass rules that allow more diversions at lower flows than May. Most Chinook species have exited the Delta by June though it may be possible that three species are still present in lower abundance. June does not receive benefits of the spring outflow criteria and is a month when Level 2 or 3 would be activated in most but the driest of water year types. Differences in survival are more pronounced in this month. Median reduction in survival under the PA is 2% with a range from 20% reduction to a 4% increase in survival. L1 offers moderate improvement over PA particularly in the 50% of years with the middle survival reductions

For information on what the analysis above means in terms of individual species and their temporal presence during these months, please refer to the Exposure and Risk section below.

Differences in Survival by Water Year Type

The Perry 2017 model shows a pattern of reduced daily survival probabilities for smolts migrating through the Delta for each month of the salmonid migration period and across each water year type under the PA with the exception of April and May in dry water year types (Figure 2). Furthermore, the boxplots below show that during at least 75 percent of the years(e.g., 75th percentile) reduced survival under the PA is estimated for each month, from October through June with the exception of April and May of dry water year types (Figure 2). Under the more protective Level 1 operations, the survival probabilities remain reduced for 75% of the years during each month of the migration period with the exception of April in dry years (Figure 3).
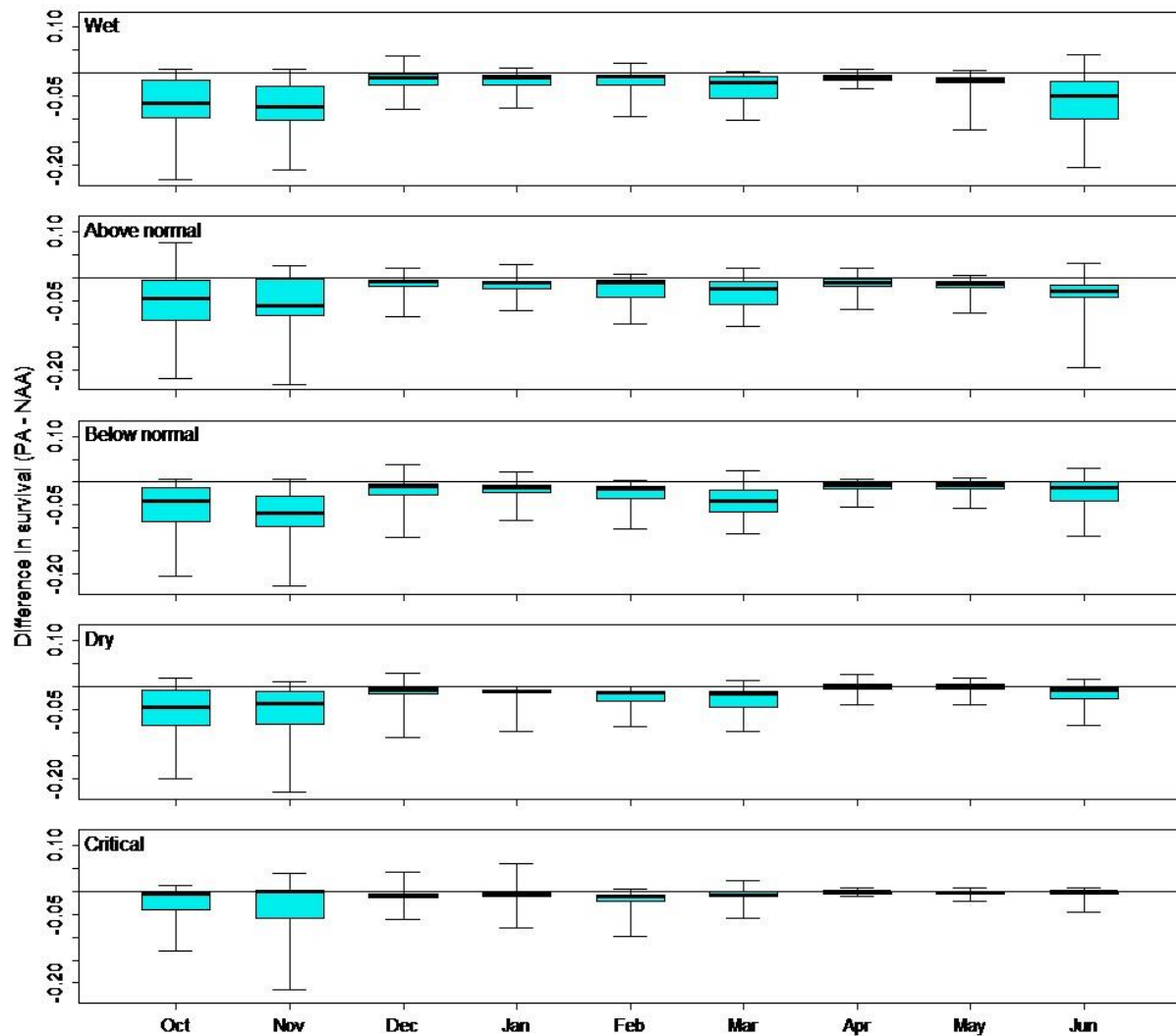
*Figure **Error! No text of specified style in document.**-19. Boxplots of differences in through-Delta survival between the PA and NAA scenario by water-year type.*

Each box plot represents the distribution of daily survival differences among years of a given water-year type and month. The point in each box represents the median, the box hinges represent the 25th and 75th percentile, and the whiskers display the minimum and maximum.
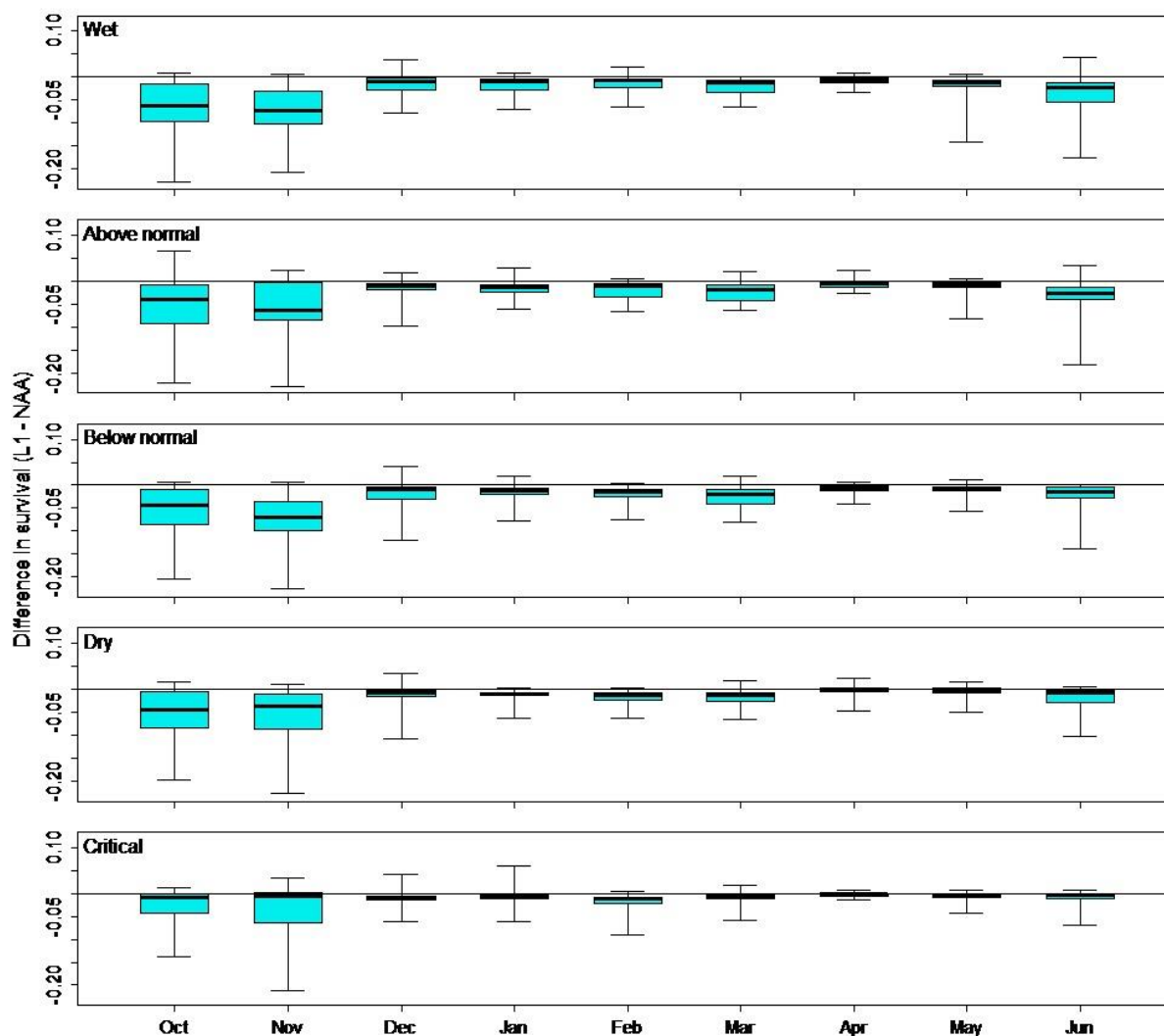
*Figure **Error! No text of specified style in document.**-20. Boxplots of differences in through-Delta survival between the L1 and NAA scenario by water-year type.*

Each box plot represents the distribution of daily survival differences among years of a given water-year type and month. The point in each box represents the median, the box hinges represent the 25th and 75th percentile, and the whiskers display the minimum and maximum.

This section will summarize how effects of PA or L1 differ among water year types. Because the NDD diversions contain minimum Bypass flows before diversions can occur it is expected that in critical or dry year types, exports may come predominantly from the south Delta facilities. Conversely, during the wetter water year types exports may come predominantly from the north Delta facilities so it is helpful to look at effects on species among the different water year types as effects will vary geographically based on operations.

The reduction in survival under the PA is greatest in wet water year types during October and November and the least reduction in survival is under critical years (Table 2-21). If listed species

are detected during these months, they would start to be managed under the May Level 1 Bypass rule. During October, survival reductions range from 0.7 in critical years to 6.6% in wet years and in November median survival reductions range from 0.2% in critical years to 7.4% in wet years. L1 operations do not differ much from PA operations due to Bypass rules remaining constant during these months unless there is a real time management trigger to initiate Level 1 pumping.

Reduction in survival of PA compared to NAA OCTOBER	Median reduction in survival	Core population reduction (interquartile)	25% of population with biggest reduction	25% experiencing lowest reduction and/or (survival increase)
Wet	6.6	9.6 to 1.5	23.1 to 9.6	1.5 to (+1.0)
AN	4.5	9.2 to 0.6	22 to 9.2	0.6 to (+7.6)
BN	4.2	8.5 to 1.1	20.6 to 8.5	1.1 to (+0.6)
Dry	4.4	8.5 to 0.7	20.1 to 8.5	0.7 to (+1.8)
Critical	0.7	4.1 to 0	13 to 4.1	0 to (+1.2)
NOVEMBER				
Wet	7.4	10.1 to 2.9	21 to 10.1	2.9 to (+0.8)
AN	6.1	8.2 to 0.3	23.3 to 8.2	0.3 to (+2.5)
BN	6.7	9.7 to 3.1	22.5 to 9.7	3.1 to (+0.7)
Dry	3.6	8.1 to 1.0	23 to 8.1	1.0 to (+1.1)
Critical	0.2	6 to (+0.3)	21.4 to 6.0	(+0.3 to +3.8)

*Table **Error! No text of specified style in document.**-21 Absolute percent change in survival over all water year types.*

For the key migratory months of December through June, the survival reduction tables are grouped by water year type instead of month. This allows a better representation of what out-migrating smolts would experience as they transit the Delta in any given water year type. The full range of differences for these months are displayed along with the months that have the largest and smallest reduction in survival under the PA. This allows for comparison between the months where the most and least concerning effects are evident.

In wet water year types, the median difference in survival during the December through June migration period is expected to be reduced between 0.8 – 4.9% under the PA (Table 2-22). For half of the wet years (i.e., the interquartile), survival is expected to be reduced by up to 10%. For 25% of the years, survival will be reduced by up to 20.5%. The remaining 25% of the years will range between a survival decrease of 1.9% to a survival increase up to 4% (Table 2-22). The two months that have the largest and the smallest survival reductions during wet years under the PA within the December to April operating rules are March and April respectively (Table 2-22). Overall, under the PA, the largest survival reduction is expected for March and June (reference boxplots (Figure 2 and/or Appendix).

*Table **Error! No text of specified style in document.**-22. Absolute percent change in survival for all months in wet water year types*

Monthly survival reduction in Wet years under PA compared to NAA	Median reduction in survival in Wet years	Reduction in survival for middle 50% of Wet years (interquartile)	Reduction in survival for 25% of Wet years (minimum to first quartile)	Reduction (or increase) in survival for 25% of Wet years (third quartile to maximum)
December to June (PA)	4.9 to 0.8	10 to 0.3	20.5 to 1.5	1.9 to (+4)
March (largest survival reduction)	1.9	5.4 to 0.7	10.2 to 5.4	0.7 to (+0.3)
April (smallest survival reduction)	0.9	1.5 to 0.4	3.4 to 1.5	0.4 to (+0.8)

In above normal water year types, the median survival during the December through June migration period is expected to be reduced between 0.9 - 3% under the PA (Table 2-23). For half of the years (interquartile), survival is expected to be reduced by up to 5.9%, and for 25% of the years, survival will be reduced by up to 19.6%. The remaining 25% of the years is expected to have either a survival reduction of 1.7% or an increase in survival up to 3.1% (Table 2-23). December, January April and May had less overall survival reduction in above normal water years then the months of February, March and June (Appendix x and/or Figure 2). The months that have the largest and the smallest survival reductions under the PA in above normal years within the December to April operating criteria are March and April respectively (Table 2-23). Overall, under the PA, the largest survival reduction is expected for February, March and June (reference Figure 2 or Appendix).

*Table **Error! No text of specified style in document.**-23 Absolute percent change in survival over all months in above normal water year types.*

Monthly survival reduction in Above Normal years under PA compared to NAA	Median reduction in survival in AN years	Reduction in survival for middle 50% of AN years (interquartile)	Reduction in survival for 25% of AN years (minimum to first quartlile)	Reduction (or increase) in survival for 25% of AN years (third quartile to maximum)
December to June (PA)	3 to 0.9	5.9 to 0.3	19.6 to 1.8	0.3 to (+3.1)
March (largest survival reduction)	2.3	5.9 to 0.9	10.5 to 5.9	0.9 to (+2.0)
April (smallest survival reduction)	1	1.8 to 0.3	6.8 to 1.8	0.3 to (+2.0)

In Below Normal water year types, the median survival during the December through June migration period is expected to be reduced between 0.7 - 4% under the PA (Table 2-22). For half of the years (interquartile), survival is expected to be reduced by up to 6.4%, and for 25% of the years, survival will be reduced by up to 12.1%. The remaining 25% of the years is expected to have either a survival decrease of up to 1.7% or a survival increase up to 3.8% (Table 2-22). April and May had less overall survival reduction in below normal water years then the other

migratory months (see Appendix x or Figure 2). The months that have the largest and the smallest survival reductions under the PA during below normal years within the December to April operating criteria March and April respectively (Table **Error! No text of specified style in document.**-22). Overall, under the PA, the largest survival reduction is expected for February, March and June (reference Figure 2 or Appendix).

*Table **Error! No text of specified style in document.**-22. Absolute percent change in survival over all months in below normal water year types*

Monthly survival reduction in Below Normal years under PA compared to NAA	Median reduction in survival in BN years	Reduction in survival for middle 50% of BN years (interquartile)	Reduction in survival for 25% of BN years (minimum to first quartile)	Reduction (or increase) in survival for 25% of BN years (third quartile to maximum)
December through June (PA)	4 to 0.7	6.4 to 0.1	12.1 to 1.4	1.7 to (+3.8)
March (largest survival reduction)	4.0	6.4 to 1.7	11.2 to 6.4	1.7 to (+2.6)
April (smallest survival reduction)	0.7	1.4 to 0.1	5.5 to 1.4	0.1 to (+0.8)

In dry water year types, the median survival during the December through June migration period is expected to be reduced by up to 1.6% under the PA with the exception of April and May where median survival is increased by 0.1% in April (Table 2-23) and equal in May. For half of the years (interquartile), survival is expected to be reduced by up to 4.6%, and for 25% of the years, survival will be reduced by up to 11%. The remaining 25% of the years is expected to either have a survival decrease up to 0.9% or a survival increase up to 3% (Table 2-23). April and May had less overall survival reduction in dry water years then other months in the migratory period (Appendix x or Figure 2). The months that have the largest and the smallest survival reductions under the PA during dry years within the December to April operating criteria are March and April (Table **Error! No text of specified style in document.**-23). Overall, under the PA, the largest survival reduction is expected for February and March (reference Figure 2 or Appendix).

*Table **Error! No text of specified style in document.**-23. Absolute percent change in survival over all months in dry water year types*

Monthly survival reduction in Dry years under PA compared to NAA	Median reduction in survival in Dry years	Reduction in survival for middle 50% of Dry years (interquartile)	Reduction in survival for 25% of Dry years (minimum to first quartile)	Reduction (or increase) in survival for 25% of Dry years (third quartile to maximum)
December to June (PA)	1.6 to (+0.1)	4.6 to (+0.5)	9.7 to 0.5	0.9 to (+3.0)
March (largest survival reduction; PA)	1.6	4.6 to 0.9	9.7 to 4.6	0.9 to (+1.4)
April (smallest survival reduction; PA)	0.1	0.5 to (+0.5)	3.9 to 0.5	(+0.5) to (+2.7)

In critical water year types, the median survival during the migration period is expected to be reduced by up to 1.2% during the months of December through June under the PA (Table 8). For half of the years (interquartile) during December through June, survival is expected to be reduced by up to 2.1%. For 25% of the years, survival will be reduced by up to 9.9% during December through June. The remaining 25% of the years is expected to have either a survival decrease of up to 0.9% or a survival increase up to 6% (Table **Error! No text of specified style in document.**-24). The months that have the largest and the smallest survival reductions under the PA during critical years within the December to April operating criteria are February and April (Table **Error! No text of specified style in document.**-24). Overall, under the PA, the largest survival reduction is expected for January, February and March (see Figure 2 or Appendix).

Median reductions in survival under the PA ranged around 1% during critical years. Diversions at the north Delta will be limited by the low inflow common in this water year type so inflows are similar between scenarios.

*Table **Error! No text of specified style in document.**-24. Absolute percent change in survival over all months in Critical water year types*

Monthly survival reduction in Critical years under PA compared to NAA	Median reduction in survival in Critical years	Reduction in survival for middle 50% of Critical years (interquartile)	Reduction in survival for 25% of Critical years (minimum to first quartile)	Reduction (or increase) in survival for 25% of Critical years (third quartile to maximum)
December to June	1.2 to 0.2	2.1 to 0	9.9 to 0.5	0.9 to (+6.0)
February (largest survival reduction)	1.2	2.1 to 0.9	9.9 to 2.1	0.9 to (+0.5)
April (smallest survival reduction)	0.2	0.5 to 0	1.2 to 0.5	0 to (+0.8)

2.5.1.2.7.5 Life Cycle Models

A state-space life-cycle model for winter-run Chinook salmon in the Sacramento River (WRLCM) was used to analyze differences between the NAA and PA Alternatives of CWF. The model has multiple stages including eggs, fry, smolts, juveniles in the ocean, and mature adults in the spawning grounds. The model is spatially explicit and includes density-dependent movement among habitats during the fry rearing stage. It also incorporates survival from the habitat of smoltification to Chipps Island from the enhanced particle tracking model (ePTM). The model operates at a monthly time step in the freshwater stages and at an annual time step in the ocean stages. Parameter estimates for the model were obtained from external analyses, expert opinion, and estimation by statistical fitting to observed data. The observed data included winter-run natural origin escapement, juvenile abundance estimates at Red Bluff Diversion Dam, juvenile catches at Knights Landing, and juvenile abundance estimates at Chipps Island. To evaluate alternative management actions, 1000 Monte Carlo parameter sets were obtained that incorporated parameter uncertainty, process noise, and parameter correlation.

2.5.1.2.7.5.1 Interactive Object-Oriented Simulation (IOS) Model

For a description on methods of the IOS model as well as results summary from the CWF BA please refer to Appendix 5D_Methods_Section 5.D.3_page 5.D_486.

5.D.3.1.1 Model Structure

The IOS Model is composed of six model stages defined by a specific spatiotemporal context and are arranged sequentially to account for the entire life cycle of winter-run Chinook salmon, from eggs to returning spawners (Figure 5.D-135). In sequential order, the IOS Model stages are listed below.

1. Spawning, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.

2. Early Development, which models the effect of temperature on maturation timing and mortality of eggs at the spawning grounds.

3. Fry Rearing, which models the relationship between temperature and mortality of fry during the river rearing period in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.

4. River Migration, which estimates mortality of migrating smolts in the Sacramento River between the spawning and rearing grounds and the Delta.

5. Delta Passage, which models the effect of flow, route selection, and water exports on the survival of smolts migrating through the Delta to San Francisco Bay.

6. Ocean Survival, which estimates the effect of natural mortality and ocean harvest to predict survival and spawning returns by age.

For the first four years of the 82-year simulation period, the starting population for both scenarios are 5,000 of which 3,087.5 are female. In the fifth year, the number of female spawners

is determined by the model's probabilistic simulation of survival to this life-stage. The model assumes all winter-run entering the Delta are smolts and that there is no flow or temperature related mortality for the river migration (RBDD to Freeport) but a mean of 23.5 percent is applied with a standard error of 1.7 percent. Once in the Delta, the smolts are now in the Delta Passage Model (DPM) (CWF BA_Section 5.D.1.2.2) component where flow, route selection, and water exports determine survival. Only timing into the Delta is altered from the standalone DPM as spawning events and temperature determine migration towards the Delta in IOS.

Egg survival was greatest in wet years and decreased dramatically in critical years as expected, but results between scenarios were similar with median egg survival for NAA at 0.990 and for PA at 0.991 (Figure **Error! No text of specified style in document.**-24).
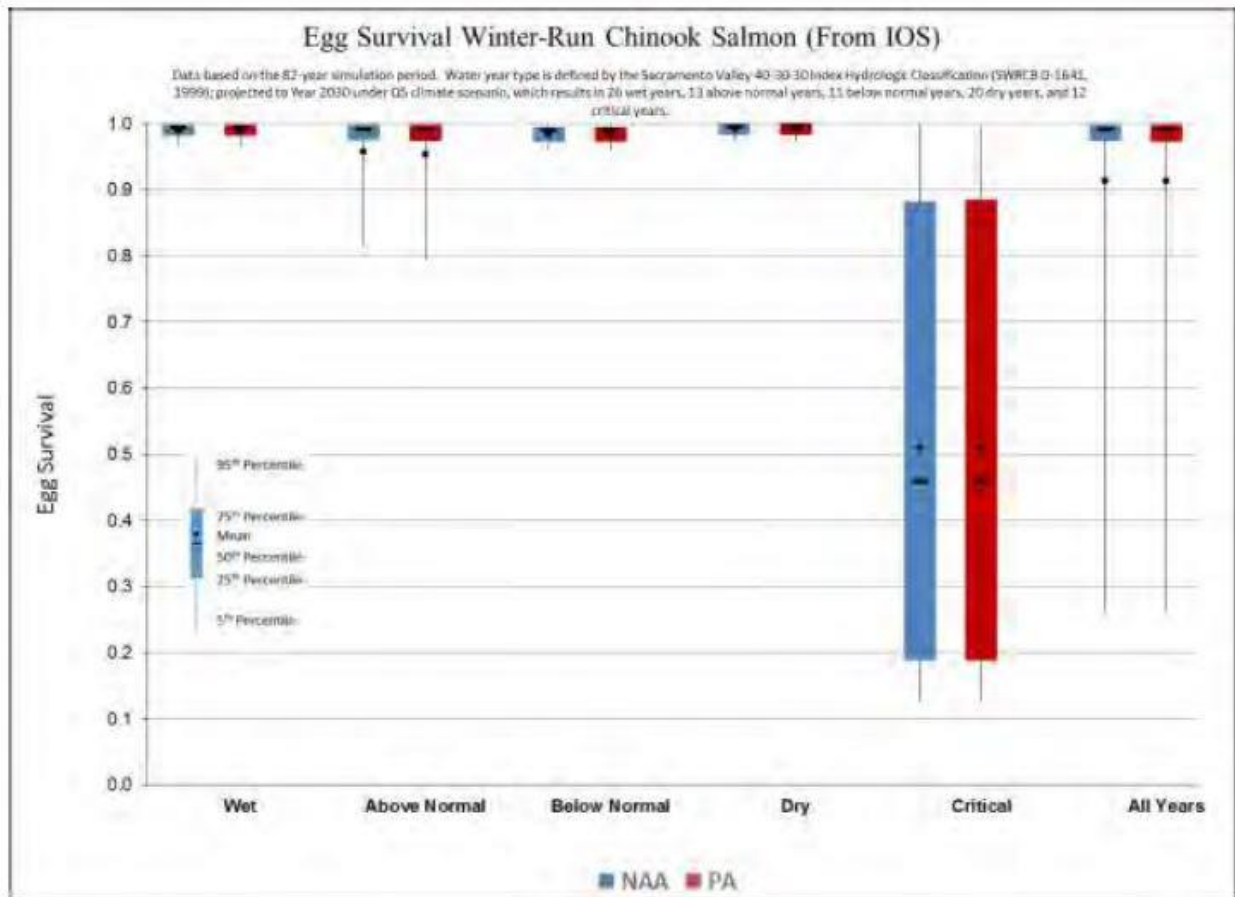
*Figure **Error! No text of specified style in document.**-24. Box Plots of Annual egg survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA)*

Likewise, fry survival from Keswick Dam to Red Bluff Diversion Dam is temperature dependent and was very similar between scenarios with median fry survival for NAA at 0.935 and for PA at 0.936 (Figure **Error! No text of specified style in document.**-25).
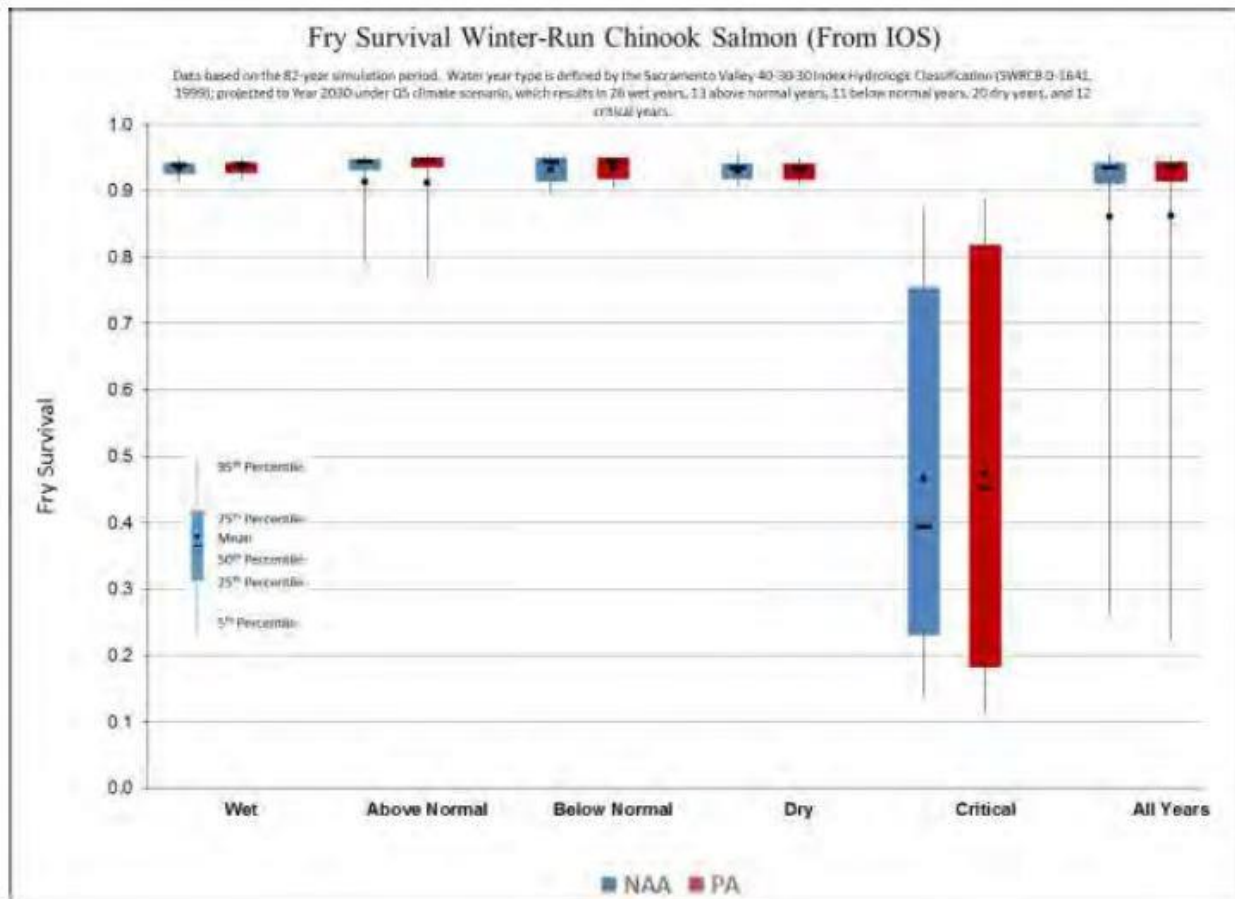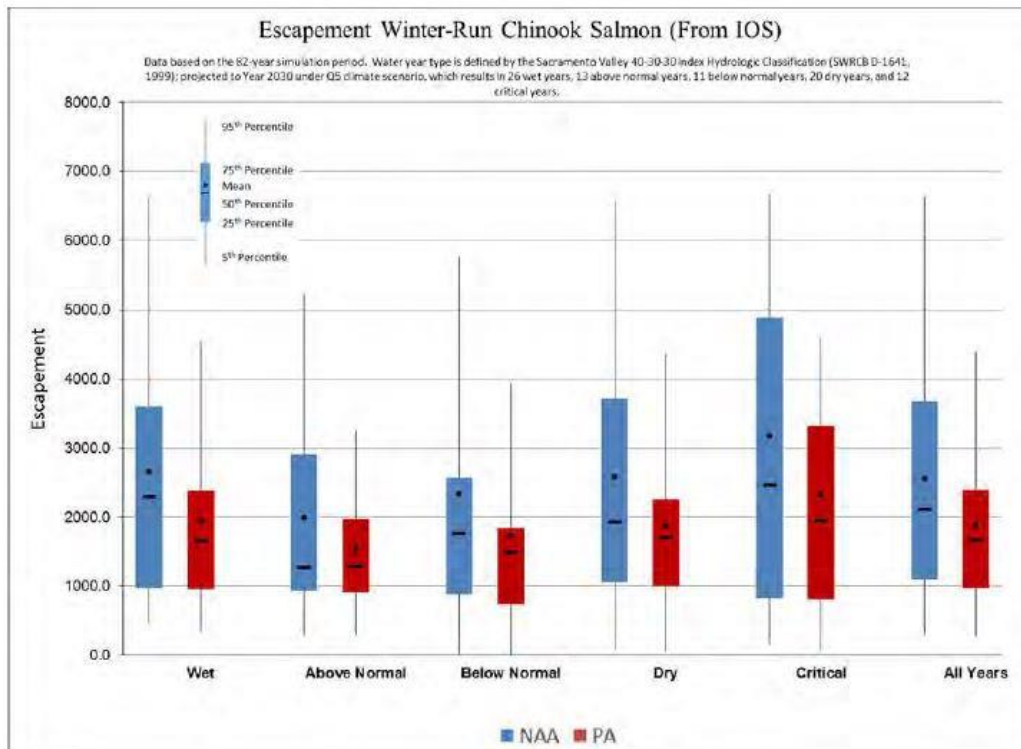
*Figure **Error! No text of specified style in document.**-25. Box Plots of Annual egg survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA)*

Through Delta Survival (From Freeport to Chipps Island) Results

Across all years, the IOS model's median predicted through-Delta survival was 0.380 for the NAA and 0.354 for the PA, a 2.6% absolute difference, which is a relative difference in survival of 7%. Across all years, the 25th percentile value of survival for the NAA was 0.306 and 0.287 for the PA which is a relative difference in survival of 6%. The 75th percentile value of survival for the NAA was 0.469 and for the PA it was 0.457 which is a 3% relative difference in survival.
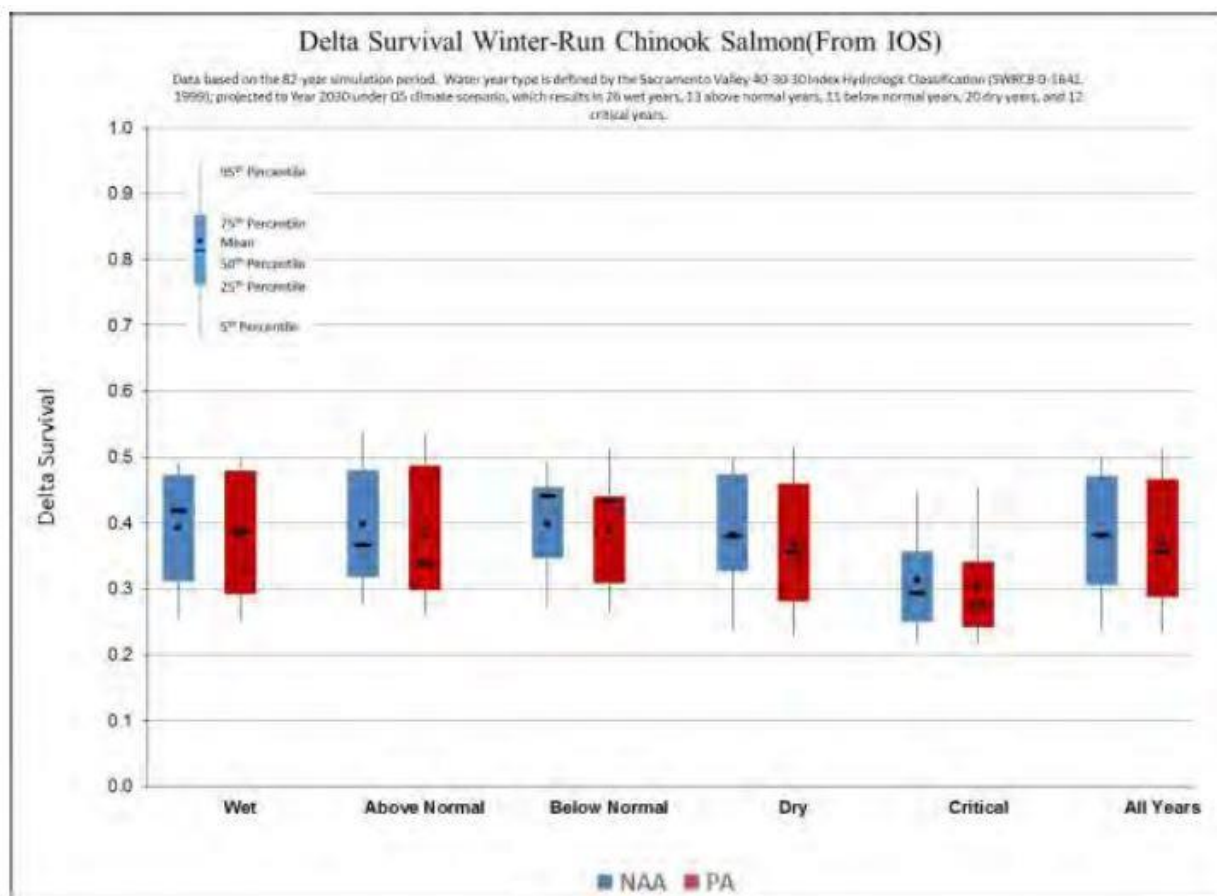
*Figure **Error! No text of specified style in document.**-26. Box Plots of Annual Through-Delta Survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).*

Escapement Results

The IOS model predicted NAA median adult escapement at 2,274 and the PA median escapement of 1,699, a population difference of 25% (Figure 5.D-149 and Figure 5.D-150). In other words, 25% reduction of adult spawners under the PA. The 25th percentile escapement for the NAA was 1,119 and 1,007 for the PA while the 75th percentile value was 3,651 for the NAA and 2,858 for the PA which is 10% and 22% percent lower, respectively.

Throughout the life cycle of winter run Chinook salmon, the IOS model identified the Delta survival to be most affected by the PA, where median survival was reduced by 2.6% translating to a relative difference of 7%. This survival deficit in the Delta is the ultimate cause of the reduced escapement seen under the PA. As stated in the CWF BA Section 5.4.1.3.1.2.1.3.4 "the IOS escapement estimates suggested that lower through-Delta survival would result in increasing divergence of PA and NAA escapement estimates. Resulting in a median 25% lower escapement estimate for the PA over the 81 years simulated."

In this model, the probability of survival in the ocean is identical between PA and NAA. IOS results show survival probabilities are similar between the two scenarios for the egg stage and the fry stage, and attributes the 25% decrease in escapement to the reduced through-Delta

survival under the PA. There were differences in escapement based on water year type but this is not a reflection of hydrologic conditions for the out migrating juveniles. It is simply a classification of hydrology for when adults returned.
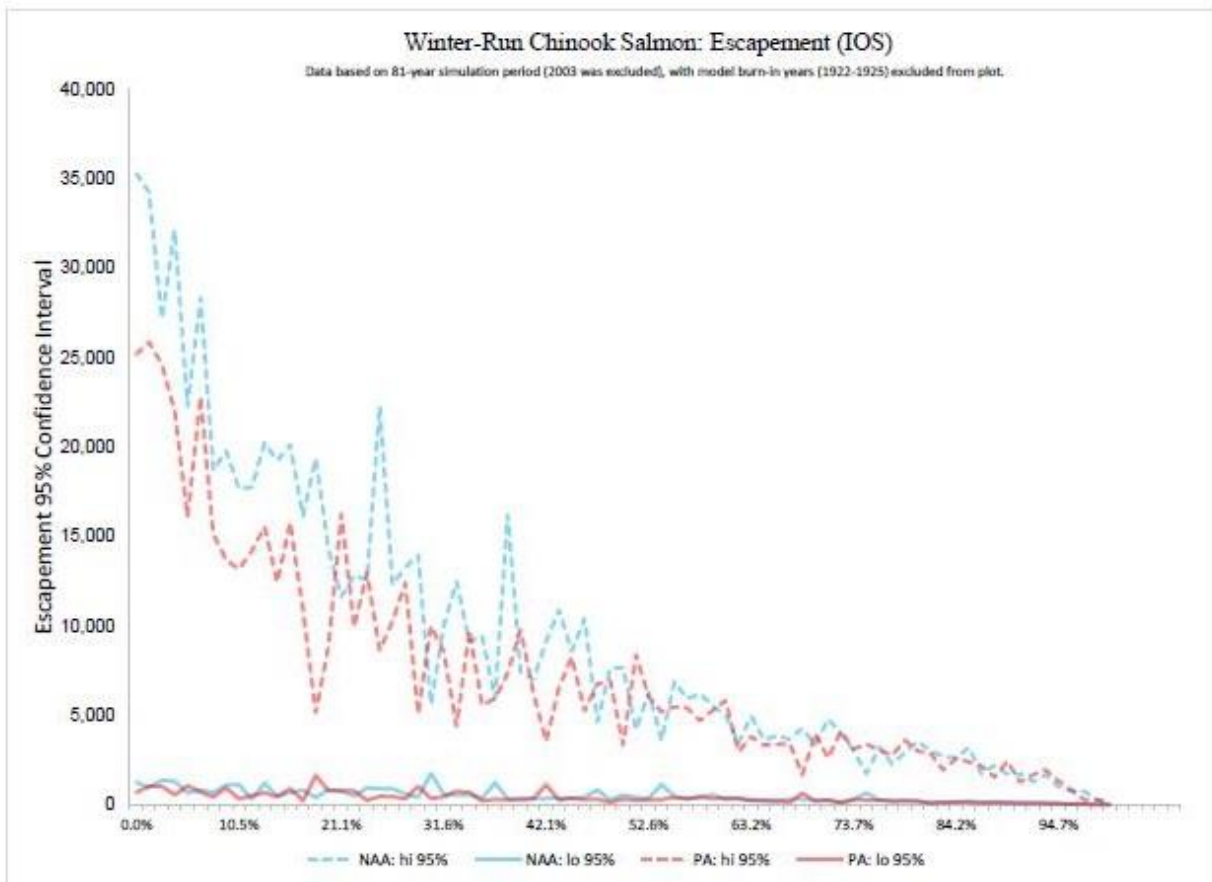

*Figure **Error! No text of specified style in document.**-27. Box Plots of Annual Escapement for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA)*

Note: Data are sorted by mean estimate, with only 95% confidence intervals shown.

*Figure **Error! No text of specified style in document.**-28. Winter-run Chinook Salmon Escapement*

2.5.1.2.7.5.2 Sacramento River Winter-run Chinook Salmon Life Cycle Model

A state-space life-cycle model for winter-run Chinook salmon in the Sacramento River (WRLCM) was used to analyze differences between the NAA and PA Alternatives of CWF. The model has multiple stages including eggs, fry, smolts, juveniles in the ocean, and mature adults in the spawning grounds. The model is spatially explicit and includes density-dependent movement among habitats during the fry rearing stage. It also incorporates survival from the habitat of smoltification to Chipps Island from the enhanced particle tracking model (ePTM). The model operates at a monthly time step in the freshwater stages and at an annual time step in the ocean stages. Parameter estimates for the model were obtained from external analyses, expert opinion, and estimation by statistical fitting to observed data. The observed data included winter-run natural origin escapement, juvenile abundance estimates at Red Bluff Diversion Dam, juvenile catches at Knights Landing, and juvenile abundance estimates at Chipps Island. To evaluate alternative management actions, 1000 Monte Carlo parameter sets were obtained that incorporated parameter uncertainty, process noise, and parameter correlation.

The No Action Alternative (NAA) and the Proposed Action (PA) were run under each of the 1000 parameter sets. It is important to note that the NAA and PA should be evaluated in a

relative sense using the WRLCM, because relative comparisons are more robust than the absolute predictions from the WRLCM. Moreover, attempts to identify the outputs of the model as equating to actual fish in the Sacramento River is incorrect. This perspective is adopted for several reasons: 1) the underlying hydrology of the NAA and the PA are CalSim model outputs that are a combination of historical hydrology and future expected hydrological conditions, but do not represent actual historic or future hydrology; 2) the WRLCM model and the models used to provide input to the LCM model that use the CalSim results (HEC-RAS, DSM2, and ePTM) require assumptions that would all need to be true; and 3) the WRLCM was not calibrated to produce forecasts of actual abundances. As a result, the WRLCM should be viewed as a tool that can provide guidance on the relative performance of the two actions, and the percent difference (PA – NAA)/NAA * 100% was computed for each of the 1000 model runs.

A detailed description of model and scenario results are contained in appendix xyx.

Scenarios Evaluated

A total of six scenarios were run for the CWF Alternatives that differed in hydrology sequencing, initial abundance and additional NDD mortality values (range 0% to 5%). The additional mortality for the new North Delta diversions incorporates mortality expected due to large in-river structures and near field diversion screen effects. There is no empirical data for diversion intakes of the size and capacity proposed in the lower Sacramento River so a range of estimates were applied. Table 1 includes key parameters of the six scenarios run for the two CWF Alternatives.

CWF Alternative (PA, NAA) Comparison	Initial Abundance	Hydrology	NDD near - field mortality	Rationale
Scenario 1	10,000	Standard	5%	original scenario run
Scenario 1A	20,000	Standard	5%	explore resiliency of larger population
Scenario 1B	10,000	Revised	5%	test more favorable starting hydrology sequence
Scenario 2	5,000	Revised	5%	explore smaller population under revised hydrology
Scenario 2A	5,000	Revised	0%	explore smaller population, revised hydrology and no near field mortality
Scenario 2B	5,000	Revised	3%	explore smaller population, revised hydrology and 3% near field mortality.

Table 1. Description of modeling scenarios analyzed.

Initial Abundance: Ranges from 5,000 to 20,000 were selected to allow exploration of varying populations to utilize the habitat and density dependent components of the model. These initial abundances are not necessarily meant to reflect current, historical or projected population trends.

Hydrology: The standard hydrology represents the 82-year historical CalSim record from 1922 to 2002. Revised hydrology represents the same 82 historical years but arranged differently so that the drought years in the 1930's occur later in the simulation run. This allows initial

populations in the model to experience extreme drought conditions only after a longer sequence of more moderate hydrologic conditions.

These scenario runs covered a range of starting populations and hydrological sequences as the historical record is not predictive of what will occur in the future. Additionally, results from the original run (scenario 1) were informative in deciding what additional scenarios could provide further insight on different outcomes between the two CWF Alternatives. As an example, under the original run, the abundance for both Alternatives diminished greatly after the succession of extreme drought years (1929 to 1937) but only the NAA population was able to recover abundance levels over the remaining time series. The PA population was not able to replace itself and therefore not able to approach initial abundance levels throughout the remaining time series. This necessitated an approach to evaluate different scenarios for the Alternatives to allow for thorough resolution of the model's habitat and survival relationships that may not have been realized under scenario 1 for the PA Alternative.

Results of Scenario Evaluations NAA vs PA

Overall, the WRLCM results indicate higher abundances and higher cohort replacement rates (CRR) under the NAA relative to the PA. Under all six scenarios, abundance was higher under NAA relative to PA through the time series. Differences between Alternatives were least for the scenario 2A in which NDD mortality was 0, initial abundance was 5,000 and hydrology sequencing was modified; these results are displayed in Figure 1. *The probability that there would be higher abundance in the PA relative to the NAA at the end of the 82-year time series was approximately 0 (Figure 1).*

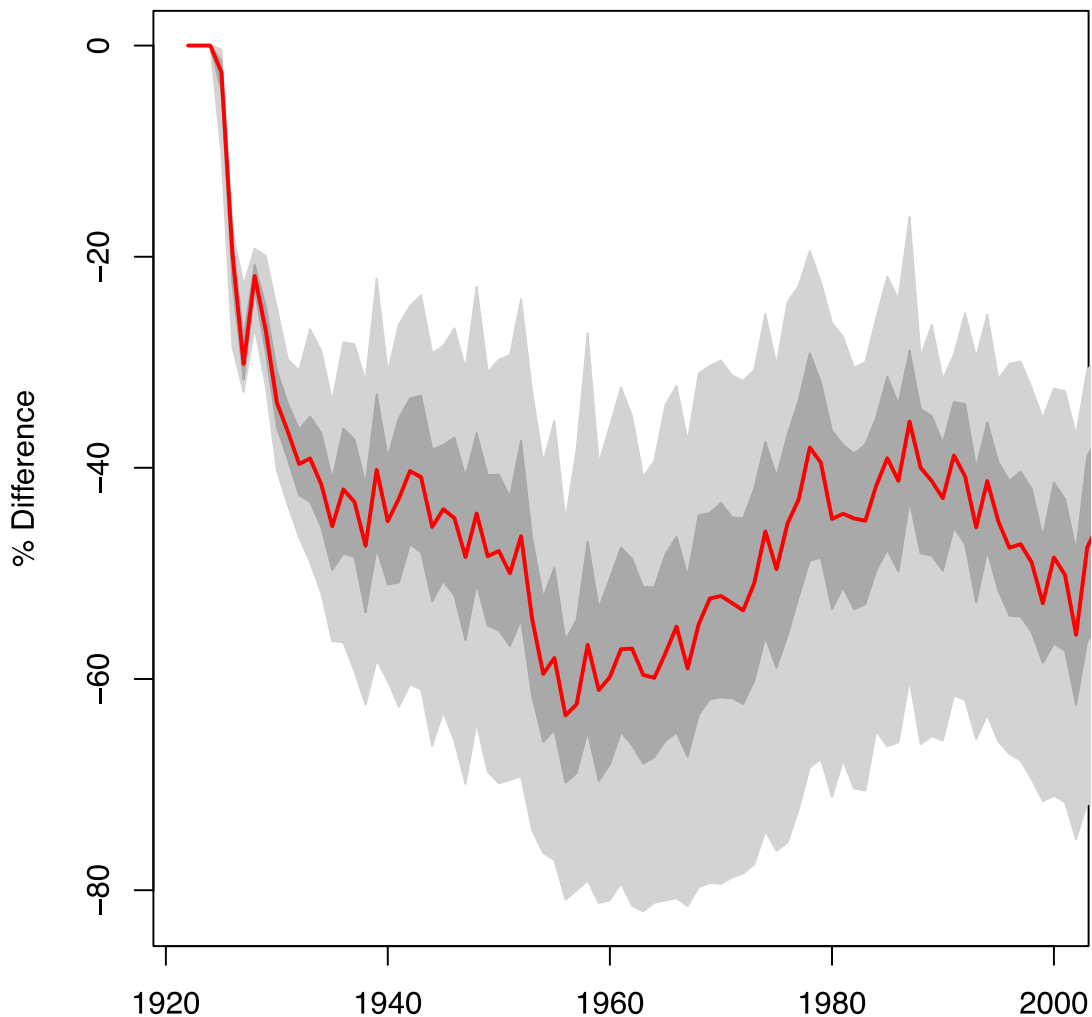## Difference in Spawner Abundance: PA and NAA Scenarios

Figure 1. Difference in Scenario 2A abundance (PA – NAA)/NAA X 100% rate for 1000 paired runs of the LCM incorporating parameter uncertainty and ocean variability (NDD = 0, Initial = 5,000, hydrology altered). Median (red line), 50% interval (dark grey) and 95% interval (light gray) are depicted.

The CRR is a key metric used to understand population dynamics, as it is the ability of a population to replace itself. In the six scenario runs, NAA always had a higher mean and median CRR than PA (Table 2). The relative difference in CRR between the alternatives averaged around 8% lower under the PA for all six scenarios.

CWF Alternative (PA, NAA) Comparison	Percent Difference in mean CRR (PA-NAA /NAA)	Percent Difference in median CRR (PA-NAA /NAA)	Pr (NAA > PA)
Scenario 1	-8.33%	-8.16%	0.998
Scenario 1A	-8.15%	-7.95%	0.998
Scenario 1B	-8.53%	-8.74%	0.998
Scenario 2	-8.78%	-8.99%	0.998
Scenario 2A	-7.48%	-7.71%	0.998
Scenario 2B	-8.24%	-8.46%	0.998

Table 2. Relative percent difference in mean and median Cohort Replacement Rate (CRR) between Alternatives and probability (Pr) the NAA CRR is greater than the PA CRR over the 1000 paired runs. Negative value in mean and median CRR indicates lower relative productivity under the PA.

Estimates of the difference in CRR for 1000 paired runs of Scenario 2A of the LCM indicated that all but 2 paired runs had higher mean CRR for the NAA relative to the PA or a probability of 0.002 (Figure 2). In other words, the population is less able to replace itself under the PA.
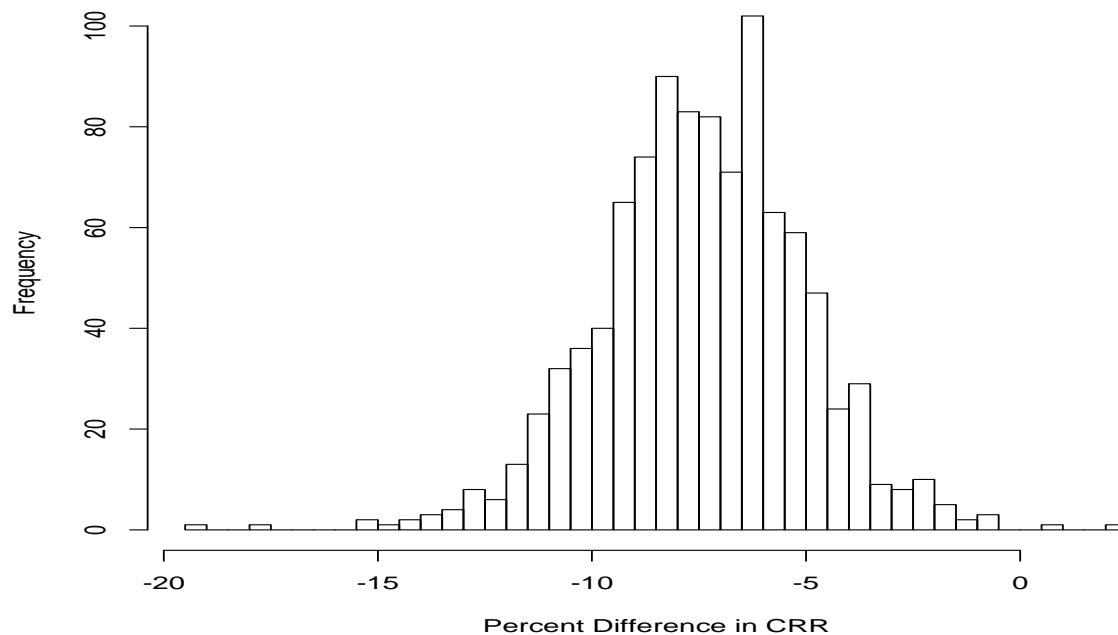
Figure 2. *Percent difference (PA – NAA)/NAA * 100% in cohort replacement rate for scenario 2A (initial abundance of 5000, NDD mortality of 0%, and hydrology time series altered).*

The probability that the CRR under PA > NA was grouped for like water year types under scenario 2A to understand whether the water year type affected CRR. The probability of having a higher CRR in the PA relative to the NAA is approximately equal in the wet water year type, but in all other year types there is a low probability that the CRR will be greater in the PA than the NAA, particularly for dry and critical years (Figure 3).
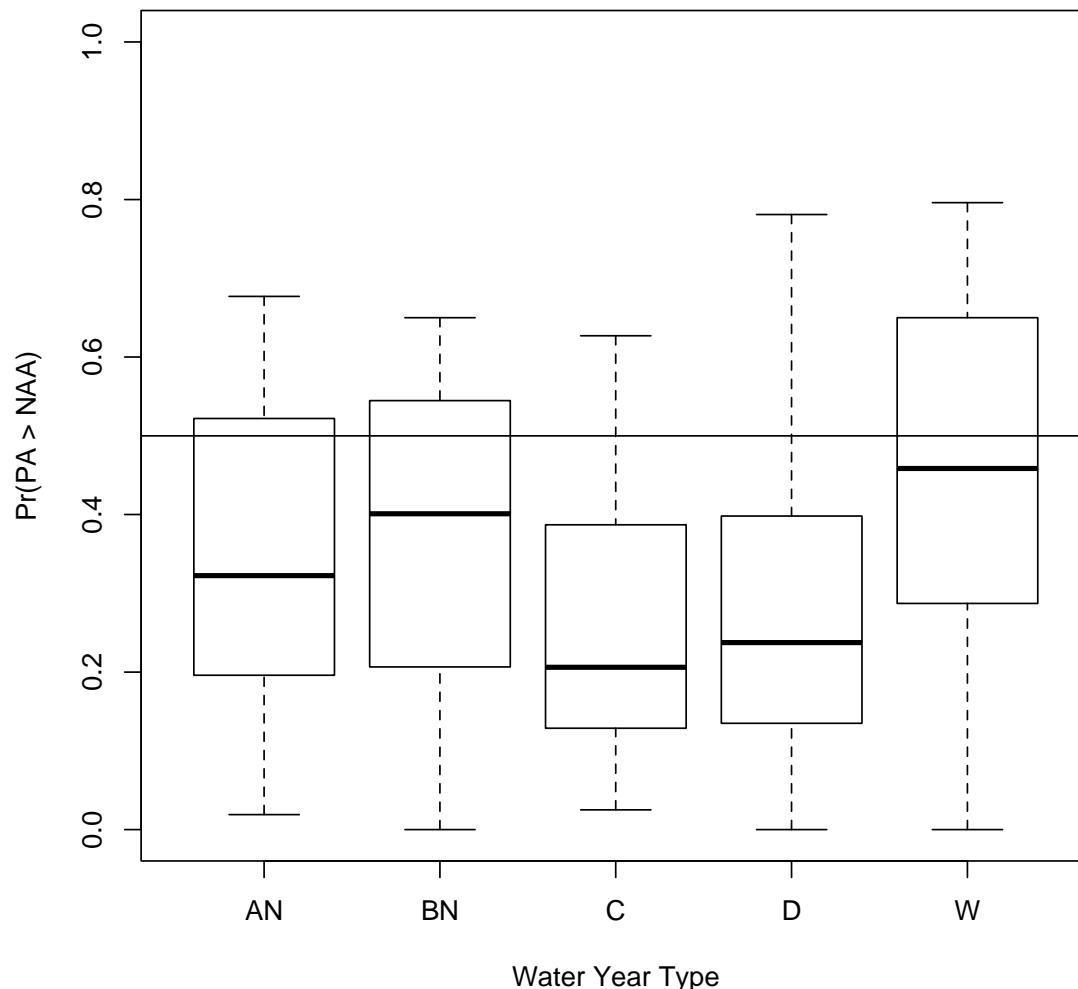

Figure 3. Probability that the cohort replacement rate under PA is greater than NAA by water year type (AN = above normal, BN = below normal, C = critical, D = Dry, W = wet) for scenario 2A (initial abundance of 5000, NDD mortality of 0%, and hydrology time series altered)

Dynamics leading to differential abundance and productivity

The lower abundance and productivity in the PA relative to the NAA are largely due to the dynamics in the Lower River and Delta habitats. There is little difference between the two alternatives in the egg to fry mortality that occurs in the reach from Keswick to Red Bluff

Diversion Dam, except for minor differences in Critical years (Figure 4). During critical years, the model showed that the PA had increased median survival in July and August by 6.4% and 1.2% respectively.
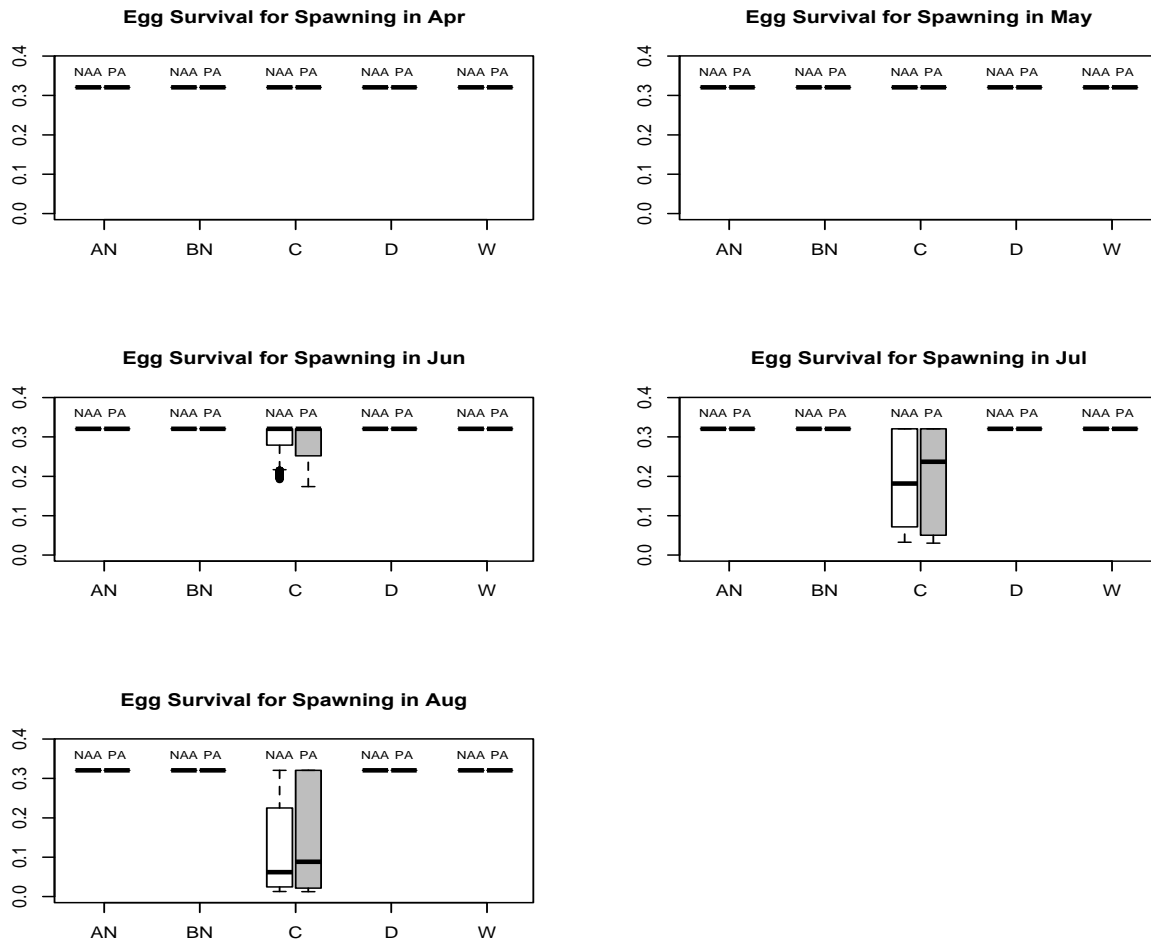

Figure 4. Egg to fry survival by month for the NAA and PA indicating relatively similar levels of mortality in NAA and PA that occur only in Critical years during June – August. Results applicable for all scenarios.

In contrast, there is moderate difference in the survival of smolts originating from the Lower River habitats (Figure 5). Under all months and water year types survival under the PA was lower except for the critical years in April where survival was similar. The month of January had lower median survival under the PA ranging from 1.2% in critical to 3.7 in dry and BN years. The month of February had lower median survival under the PA ranging from 2.2 in critical years to 7.0% in dry and BN year types. The month of March had the largest reduction in median survival under the PA ranging from 4.7 in wet to 9.2 in BN years. The month of April had the lowest median survival reduction under the PA ranging from 0.04% in critical years to 3% in BN years. The month of May had lower median survival under the PA ranging from 2% in BN years to 2.6% in dry years. The differences in smolt survival in the PA relative to the NAA reflect differences in flow in the North Delta. Under the PA, North Delta diversions reduce the flow

relative to the NAA. The ePTM survival estimates incorporate these flow dynamics leading to reduced survival in this habitat type under PA. As a result, smolts that originate from the Lower River habitat and then out migrate through the Delta will have higher survival under the NAA than the PA.
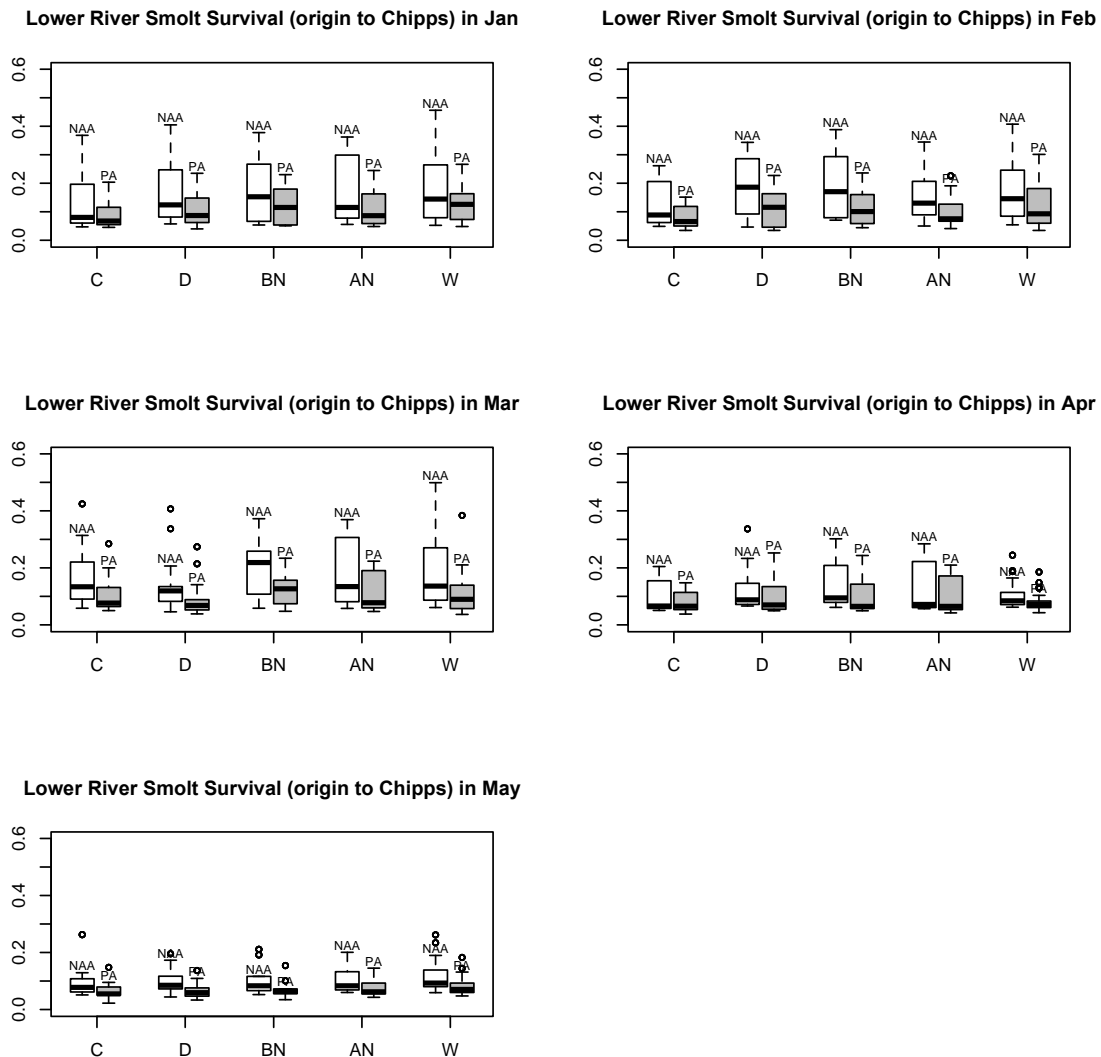

Figure 5. Monthly survival of smolts originating from the Lower River habitat under NAA and PA. In general, survivals of the PA are lower than NAA for a given water year type and month. Results applicable for all scenarios.

There is similar survival for smolts originating from the Delta between the two scenarios (Figure 6). Overall, smolts that originate in the Delta have slightly higher median survival under the PA during most months and water year types. All survival increases under the PA are under 1% with the exception of wet years where median survival increase under the PA is 2% in January and 2.2% in March and BN years where median survival increase under the PA is 1.1% in February and 1.2% in April. Any median survival increase under the NAA is less than 1%.
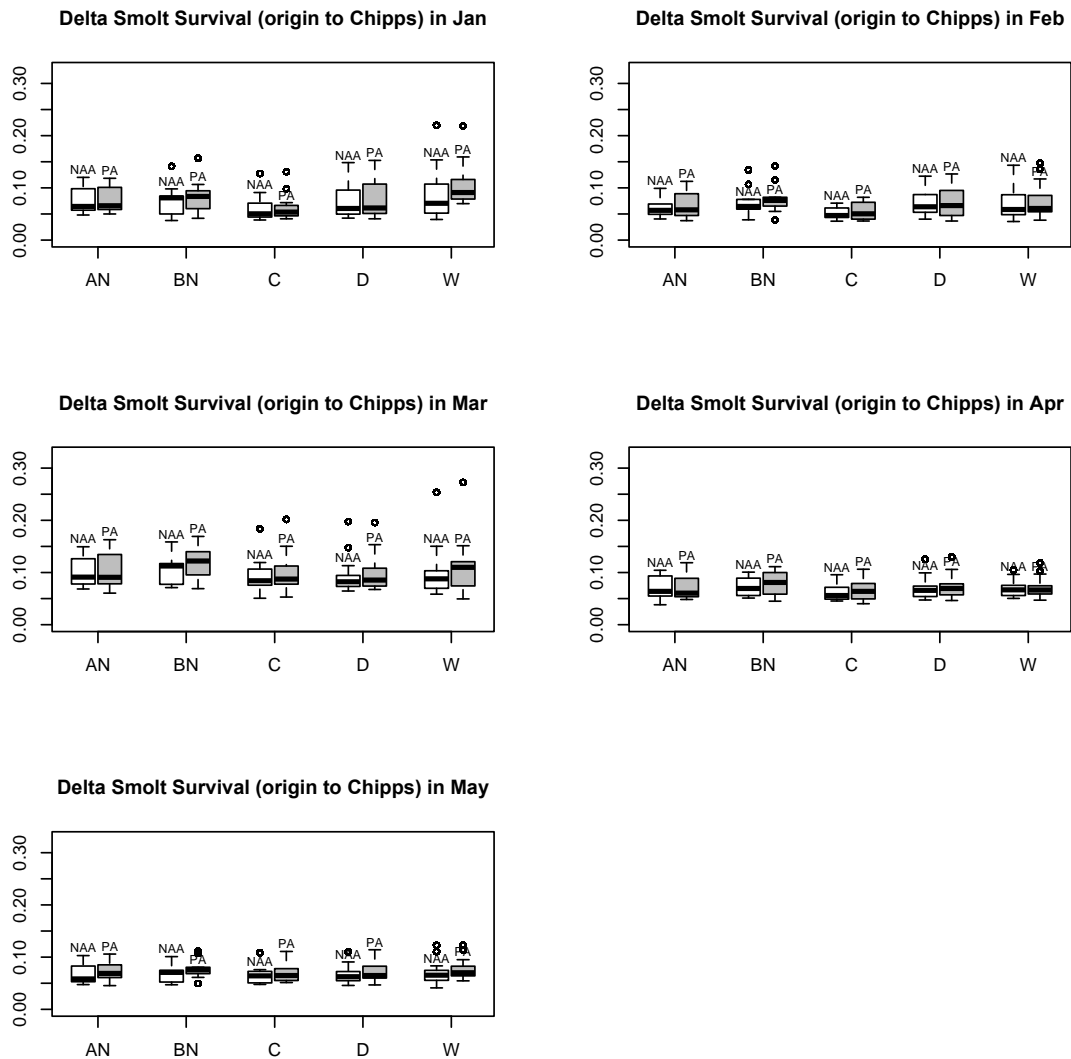
Figure 6. Monthly survival of smolts originating from the Delta habitat under NAA and PA. In general, survivals of the PA are slightly higher than the NAA during most months and water year types. Results applicable for all scenarios.

Thus, the largest difference between alternatives is the survival in the Lower River. Whether this difference will affect the population dynamics in the WRLCM depends on the proportion of smolts that originate from the Lower River habitat compared to those that originate from the Delta habitat.

Smolts do in fact originate from the Lower River habitat, and constitute the highest proportion among all five habitats with Scenario 2A shown as an example (Figure 7). This pattern is true across different water year types in both the NAA and PA. Smolts originate from the Lower River habitat in large proportions because they move there as fry and rear in that habitat until undergoing smoltification. Fry move into the Lower River from the Upper River over the September and October periods consistent with patterns in juvenile passage at Red Bluff

Diversion Dam. Fry move out of the Lower River habitat into the Floodplain habitat when there is flow into the Yolo bypass. Fry move out of the Lower River to the Delta habitat as a function of a flow threshold at Wilkins Slough (Wilkins flow > 400 m^{3}s^{-1}), which causes approximately 35% of the fry to move into the Delta in the month that the flow is above the threshold. Density dependence can also cause fry to move into the Delta; higher abundances of fry in the Lower River are closer to the carrying capacity thus leading to density dependent movement into the Delta and Floodplain if it is available. The higher proportions of smolts originating from the Delta in the NAA relative to the PA across all water year types (Figure 7) are due in part to this density dependent mechanism.

Proportion of Smolt in Each Habitat by Water Year Type
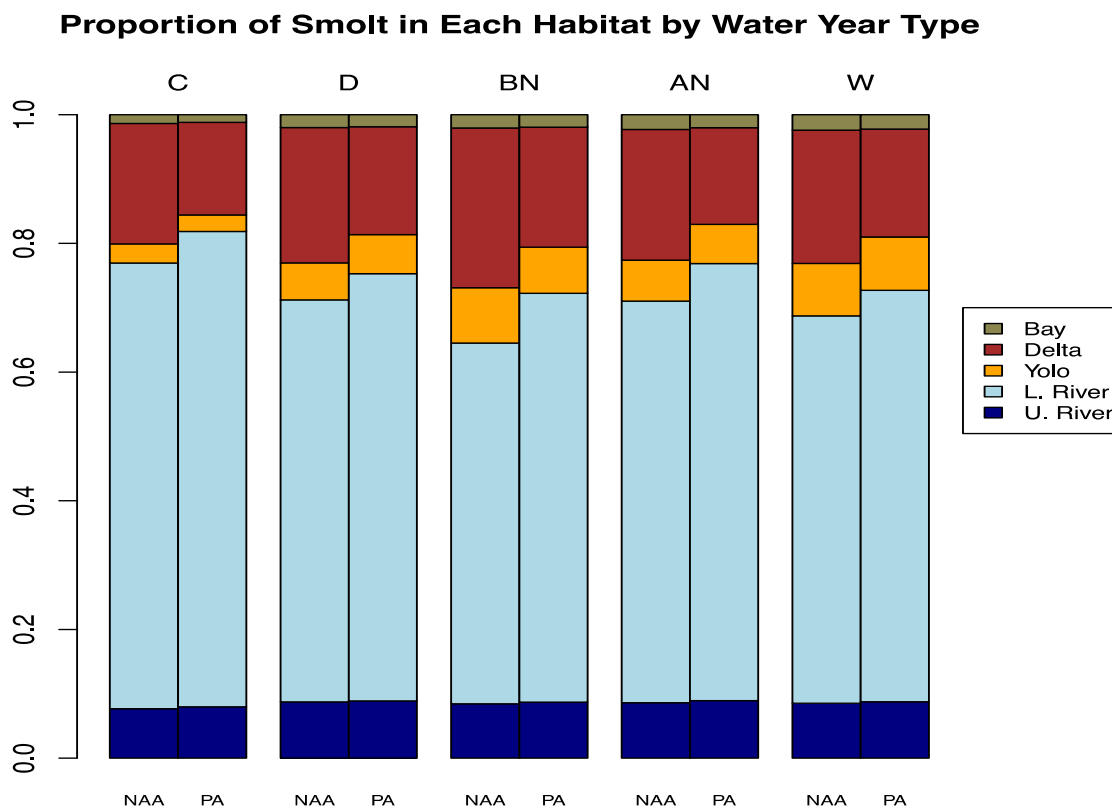
Figure 7. Origin of smolts by water year type under NAA and PA. Colors represent the habitat of origin. Values represent median levels for scenario 2A (initial abundance of 5000, NDD mortality of 0%, and hydrology time series altered).

This difference in survival between the NAA and PA for the Lower River habitat is causing lower freshwater productivity under the PA relative to the NAA with Scenario 2A shown as an example (Figure 8). These differential patterns in habitat use and differential habitat-specific survival rates translates into lower cohort replacement rate (CRR) and lower abundance in the PA relative to the NAA. This pattern is consistent across all six scenarios and across the range of parameter uncertainty used in the WRLCM simulations.

Smolt (in Gulf) per Spawner from Each Habitat, by Water Year Type
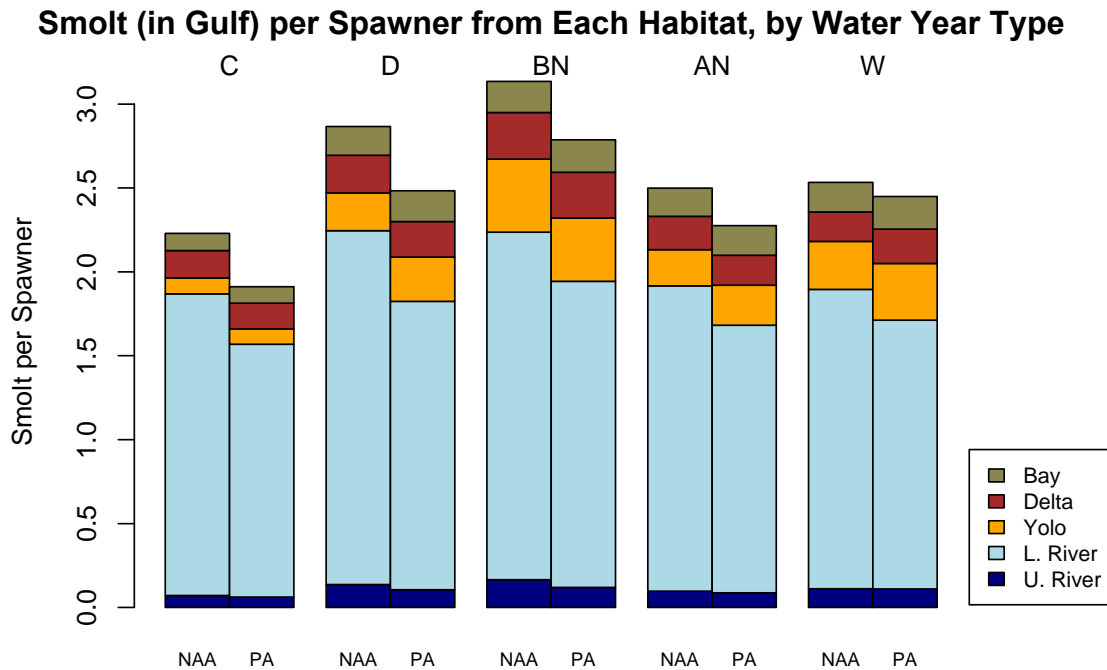

Figure 8. Productivity in the freshwater (number of juveniles in the Gulf per spawner). Colors represent the habitat of origin. Values represent median levels for scenario 2A (initial abundance of 5000, NDD mortality of 0%, and hydrology time series altered).

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